A Study of the Effects of Current and Proposed Restraint Concepts on the Child Occupants of Vehicles

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Doctor of Philosophy

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ABSTRACT

This research evaluates the performance of automotive child restraint systems (CRS) that conform to international proposals for a universal restraint concept to be adopted by both restraint and vehicle manufacturers. The concept is known as Isofix (International Standards Organisation FIXing), and is intended to ensure optimum compatibility and coupling between vehicle and CRS.

In order to quantify the benefits of the proposed Isofix concept it has been necessary to establish the performance limits and benefits offered by current commercially available adult belt retained CRS. A considerable body of knowledge existed on the performance and limitations of the then current CRS. However, during 1995 a significant amendment was introduced affecting ECE R44, the compliance standards applicable to CRS in Europe to which most manufacturers require their products to conform (separate national standards also exist). In 1995 amendment 03 was added to ECE R44 and became a catalyst for considerable development activity by manufacturers of child restraints, that resulted in new or revised product ranges. These new products, in particular forward facing Group 1 (9-15 kg) child restraints have significantly improved dynamic performance in frontal impacts, notably in modern vehicles whose seat belt anchorage positions have been optimised for restraint of adults, but are commonly less effective in restraining framed CRS. It was important therefore to re-assess existing systems as the baseline for a realistic evaluation of the proposed Isofix concepts (chapter 10).

It was evident that, of the different Isofix concepts being proposed, no overall evaluation of their relative performance had, to that date, been undertaken. A programme involving the design and manufacture of not only suitable test equipment but, in a number of cases, prototype devices, was undertaken. The resulting data have formed the basis of input to the ISO Working Group 1, the body responsible for the evolution of the Isofix concept. This programme also highlighted a number of shortfalls in the proposed concepts. The major results of this test programme have been published at international level, and were used to inform the Isofix discussions.

During the programme of comparative evaluation of not only the Isofix but the current belt retained devices, it became clear to the writer that in a frontal impact the orientation of the

occupant with respect to the direction of travel had significance. A literature survey produced evidence of minimal research in this area. Hence it was decided by the writer to include a programme of parametric tests to investigate the significance of occupant orientation, given that commercially available CRS often include a feature to vary the recline angle of the seat. The Isofix set-up was particularly suitable for this exercise in that it eliminated many of the variables associated with belt retained devices. The results of this work have been published at international level.

A review of the available accident data indicates that side impacts are potentially more life threatening than the more common frontal impacts due to the proximity of the occupant to an intruding vehicle or object. However, current European certification standards do not require the evaluation of CRS in a side impact. This is considered to be an area where improvements, particularly aided by an Isofix type attachment concept, can be made. Therefore the final area of research undertaken by the writer was to develop and propose a test to evaluate CRS in a realistic side impact scenario. This involved the simulation of not only the acceleration imparted to the target vehicle occupant but in addition the intrusion component. This work, which again has been presented at international level, contributed towards a proposal to amend the European certification standard for CRS to include a side impact evaluation.

This thesis commences with a review of the accident data currently available, and looks at how the physiological and anatomical properties of the child, vehicle design, and the inherent potential for misuse and mis-installation of the current generation of CRS, impact upon child safety. This is followed by an overview of the Isofix proposal before the results of the writer's detailed testing of both current belt retained and proposed Isofix CRS concepts (chapters 10 and 11) are reported. The subsequent chapters (12 and 13) detail the results of the writer's investigation into CRS orientation in a frontal impact and the development of a representative side impact test, based on a single sled, for inclusion in the European certification procedure. The document concludes with discussion and conclusions relating to the future of CRS design and evaluation.

The major findings of this research were:

- contrary to initial expectations, significant CRS recline angle in a forward facing device has been proven to be undesirable;

- Isofix CRS with rigid lower anchors have been shown to be beneficial, particularly in side impacts, their efficacy in a forward impact being compromised by rotation in devices that do not incorporate an anti-rotation device;

- a side impact test has been developed which more accurately represents the input to a CRS seen in a rear vehicle incident. Such a test is not only desirable but essential to drive CRS manufacturers into improving side impact protection for occupants.

ACKNOWLEDGEMENT

During the period of my research at the Road Safety Engineering Laboratory I received valuable advice, help and support from many people. I would like to record my thanks to all, and in particular to:

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Mr Geoff Savage and Mr Chris Witherington - Senior Technicians at the Road Safety Engineering Laboratory, Middlesex University.

Mr Ken Hill, Principal Lecturer, Middlesex University. Supervisor.

The Transport Research Laboratory, Crowthorne, Berkshire for providing prototype Isofix CRS and for permission to include published results of work completed under contracted to TRL and selected photographs.

Dr Jocelyn Pedder, President of Rona Kinetics, Canada, for providing prototype Isofix (Canfix) CRS.

Mrs C Mitchell, Managing Director Jeenay plc, a major UK CRS manufacturer, for providing both conventional CRS and component parts for Isofix CRS.

This research was completed at the Middlesex University's Road Safety Engineering Laboratory, utilising the dynamic sled test facility.

AUTHOR'S DECLARATION

Whilst all of the work contained in this thesis was conducted by the writer, some of the work has previously been presented elsewhere by the author, or co-written with the author, in the form of conference papers or detailed reports to the sponsors of the work.

The following represents the work conducted between October 1994 and August 1998. During that period, the following papers were presented:

- The Frontal Impact Performance of Child Restraint Systems (CRS) Conforming to the Isofix Concept. I P Paton, A P Roy, Middlesex University, and A K Roberts, Transport Research Laboratory, 1996. 15th ESV Conference, Melbourne, Paper No. 96-S3-W-23. p549-557.
  [See appendix 1]

- The Frontal Crash Performance of a Child Restraint System (CRS) as a Function of Seat Geometry, using Isofix Anchorages. I P Paton, A P Roy. 1997 International IRCOBI Conference on the Biomechanics of Impact, Hannover, Germany. p451-453.
  [See appendix 2]

- A Comparison of the Performance of Dedicated Child Restraint Attachment Systems (Isofix) R Lowne, Transport Research Laboratory, A P Roy and I P Paton, Middlesex University 1997 STAPP Conference, Orlando, Florida, Paper No. N-007. Child Occupant Protection 2nd Symposium Proceedings p71-85.
  [See appendix 3]

- Development of a Sled Side Impact Test for Child Restraint Systems. R Lowne, Transport Research Laboratory, A P Roy and I P Paton, Middlesex University. 16th ESV conference Windsor Ontario 1998, Paper No. 98-S10-09. Vol. 3 p 2179-2184.
  [See appendix 4]

The following test reports have also been issued by the author:

- Investigation into the dynamic response of, and loads imparted by, the proposed Isofix Child Seating System - July 1995.

- Report detailing the dynamic response of, and loads imparted by, the Canfix Child Seating System attachment concept during ECE R44 frontal impacts (a) Forward facing child restraint (3 year old occupant), (b) Abdominal Shield booster cushion (3 and 6 year old occupant) - August 1995.

- A summary of testing of standard conventional lap belt retained, 4 point Isofix and Canfix type booster cushions conducted in accordance with the dynamic requirements of ECE R44 03 using a TNO P6 manikin - February 1997.

- A summary of the development of a simulated side impact test incorporating deformable vehicle side structure - April 1997.

- Establishment of the crash performance envelope required for energy absorbers for child restraint systems (Department of Transport Link Project) April 1999.
  [See appendix 5]

In addition the writer played a significant part in the design and development a range of CRS for a major UK manufacturer to meet the amended European acceptance standard ECE R44 03.

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GLOSSARY OF TERMS

AIS	Abbreviated Injury Scale
ATD	Anthropomorphic test device (Manikin).
Buckle crunching	A tendency for the adult restraint buckle to be loaded in bending rather than tension during an accident due to its location on a CRS frame.
CR Point	The cushion reference point (where the planes of the seat cushion and seat back meet).
CRS	Child Restraint System.
3 ms	Three millisecond - this relates to the period of time as defined in ECE R44 at which peak accelerations of the manikin are cropped, and is intended to represent a period of time over which it has been determined a human body does not register peaks or spikes on a deceleration response trace.
CG	Centre of Gravity.
CVS	Crash Victim Simulation
EASi-MAD	'Windows' for MADYMO
ECE R44	Economic Commission for Europe Regulation number 44 - Uniform Provisions Concerning the Approval of Restraining Devices for Child Occupants of Power-Drive Vehicles ("Child Restraint System").
ECE R44-03	Third amendment to the ECE R44.
FF/ff	Forward facing
g	Acceleration due to gravity (9.81 m/s^2)
GSI	Gadd Severity Index.
Head Excursion	This term is used, as in ECE R44 to describe the further most distance beyond the test seat CR point travelled by the manikins head extremity.
Head Travel	This term is used to describe the maximum distance travelled by a manikin body segment (target to target) pre impact to maximum travel.
HIC	Head Injury Criterion.
HMSO	Her Majesties Stationary Office
km/h	Kilometres per hour
KSI	Killed or Seriously Injured

IP	Instrument Panel
LHD	Left hand drive
MADYMO	MAthematical DYnamic MOdel. Dynamic occupant modelling package produced by TNO
MAIS	Maximum Abbreviated Injury Scale
Mis-installation	Failure to correctly attach the CRS in line with the manufacturers instructions
Misuse	Failure to correctly use the CRS.
mph	Miles per hour
ms	Milliseconds
m/s	Metres per second
N/kN	Newtons/kilo Newtons (N x 10^3)
NHTSA	National Highway Traffic Safety Administration
OE	Original Equipment.
RAGB	Road accidents of Great Britain
RF/rf	Rear facing
RHD	Right hand drive
Roll out	The tendency for the upper torso of a manikin/child to roll over the top of the diagonal belt in an adult lap and diagonal restraint.
RSEL	Road Safety Engineering Laboratory, Middlesex University.
SIR	Supplementary inflatable restraint (air bag).
STATS 19	Data returned by police forces relating to road injury accidents
Submarining	Situation where an occupant slips under the lap section of a restraint
TNO	Instituut voor wegtransportmiddelen (Dutch Transport institute)
TRL	Transport Research Laboratory (formally Transport and Road Research Laboratory).
TT/tt	Top tether
Tumble home	The inward curvature of a motor car body/door glass above the waist-line.

2D	Two dimensional
3D	Three dimensional

1. AIMS AND OBJECTIVES

Aim :

The aim of this research was to study the effects of current (1994-97) and proposed Isofix restraint concepts on the safety of child occupants of vehicles.

Objectives :

- To assess the performance characteristics of currently available Child Restraint Systems (CRS) and to demonstrate the compatibility of these systems with vehicle restraint geometry. This entailed evaluating the dynamic performance levels of CRS when subjected to a standard test with a standard test seat/belt geometry. The standard used for evaluations was where applicable the European acceptance standard for CRS ECE R44.

- To compare the performance of existing Child Restraint Systems with the proposed Isofix systems and to identify any potential problems with the Isofix systems.

- To identify deficiencies in test methods for evaluating CRS performance and to recommend improved test procedures.

The aims were achieved through :

- Evaluation of CRS types existing at the commencement of this study with modern vehicle restraint geometry, combined with CRS modification to improve the interface.

- Detailed assessment of the affect of CRS geometry on the performance of existing and proposed child restraint systems.

- Critical evaluation of performance characteristics of alternative Isofix attachment concepts

- Development upon a single test sled of a dynamic test for the simulation of vehicle to vehicle impacts to evaluate CRS performance in side impact.

The original content in the work conducted is as follows :-

- Detailed assessment of seat geometry affecting both current and proposed CRS performance.

- Comparative assessment of the performance offered by the various competing Isofix attachment concepts, highlighting the advantages and shortfalls of the systems.

- Development of a dynamic rig test to simulate the events experienced in a vehicle to vehicle side impact with particular emphasis on CRS evaluation.

Further original work was carried out in the development and assessment of an energy absorber to complement and enhance the performance of the proposed Isofix attachment concepts with respect to minimising neck loading and rebound energy levels.

2. INTRODUCTION

Injuries occur to vehicle occupants as a result of acceleration levels and forces induced by them exceeding tolerable limits. Vehicular occupant restraint systems are designed to work in conjunction with automobile structures to mitigate the high levels of acceleration that may occur during an accident and, consequently, eliminate or reduce the possibility of injury.

High performance motor cars can subject occupants to mean acceleration levels of up to 1 g when accelerating, braking or cornering. These low acceleration levels are sufficient to make an occupant restraint desirable for comfort, but not essential. In an accident with a frontal impact velocity of 50 km/h (13.9 m/s) and an occupant stopping distance of 1 m the occupant may be subject to mean deceleration forces in the order of 10 g, but if the stopping distance were 0.1 m, the mean deceleration would be ten times greater. Levels approaching this magnitude in an occupant can cause life threatening injuries, and require measures to be built into vehicles if these are to be mitigated.

All vehicle/restraint system combinations attempt to permit maximum forward movement at as near a constant (hence minimal) deceleration rate as possible, whilst preventing contact between the occupant and vehicle structure. Any contact between the occupant and vehicle interior may produce high localised deceleration forces on the body part in contact and may induce excessive forces in any connecting joint or limb, as with head contact and resulting neck loads.

The primary restraining medium employed in vehicles are belts to secure the occupant to the structure. Belt restraint systems are designed to channel loads to the pelvis and chest, the more rigid parts of the body, although neither is ideal for the purpose. This is because excessive belt loading across the chest may cause rib fracture and lung puncture injuries whilst a belt riding up over the pelvis may cause abdominal injuries. Furthermore, relative motion of the unrestrained head with respect to the torso has the potential to cause injury to the upper spine by hyperextension or hyperflexion.

It is evident, therefore that restraint system design is complex, in that it must balance decelerating forces and forward movement. Designers aim to minimise the frequency and severity of impact injuries by keeping all sections of the body within or as close as possible to tolerable limits. To produce a restraint system to function optimally in all types of impact is unrealistic considering the variety of impact circumstances and occupant parameters of age and size/mass. The many elements of any restraint system should complement one another and ideally be designed to suit the deformation characteristics of the vehicle in which they are installed.

Adult occupant restraints have been available since the 1950's, but dedicated child restraint systems (CRS) were not developed until the early 1960's. This study addresses the performance of dedicated child restraints with the aim of improving the protection of child occupants in road traffic accidents.

CRS development is driven by, and has been a consequence of, statutory regulations. Currently, commercially available systems of the 'universal' type may be fitted to most vehicles by means of the vehicle's adult belt system for greater user convenience. This universality is however, regressive; dynamic performance has been compromised to the extent that these systems are now potentially inferior to earlier systems that used dedicated straps to attach them to the vehicle.

There are two recognised deficiencies with the current generation of adult belt retained CRS. Firstly the complex adult belt routing to secure the CRS allows the possibility for mis-installation. Secondly, the use of the adult restraint system, even when employed correctly, results in significantly inferior retention of the CRS to the vehicle structure (and hence potentially greater head excursion) than would be the case with dedicated straps, or better still rigid anchors. These deficiencies are compounded by the increasing popularity of compact cars with smaller seat size and reduced interior space and further compounded by the recent introduction of retractor belt systems and revised adult belt geometry.

A more rigid attachment of the CRS to the vehicle structure was proposed in the early 1990's. This concept became known as Isofix (International Standards Organisation fixing) and is a universal system of CRS attachment to be fitted to all vehicles. The concept is endorsed by CRS manufacturers, vehicle manufacturers and national agencies with a co-ordinated international programme of research, development and test programme to evaluate the dynamic performance characteristics and to assess public acceptability.

CRS dynamic performance must comply with national and international standards. The universal European acceptance standard is ECE R44 [2.1], controlled by the United Nations which embraces many aspects, such as the quality of written instructions, toxicity of materials, strength/durability of component parts and dynamic performance in impact. The standard is being amended on an on going basis to reflect changes in the field, and the current version of the standard is ECE R44 03 (amendment 03). Amendment 03 to the ECE R44 standard was enacted during this study and is the reference standard used in this research. In both Europe, and world wide, dynamic performance tests are confined to frontal and rear impacts using a simulated vehicle seat and a standard adult restraint. Dynamic performance testing in side impacts is not a requirement at present in the ECE R44 regulation and only in a small number of territories are oblique impact simulations presently conducted [2.2] [2.3].

The aim and objectives of this research were to evaluate and enhance the dynamic performance of CRS using the Isofix concept. A secondary objective was to devise a representative side impact test regime to complement the ECE R44 front and rear impact requirements. Finally, it became apparent during the research programme that greater knowledge was desirable relating to the efficacy of reclining CRS (common in the market place), with respect to the effect on dynamic performance in a frontal impact.

3. UK ROAD ACCIDENT STATISTICS, LEGISLATION AND COMPLIANCE, USAGE AND MISUSE RATES, IMPACT TYPES AND INJURIES

Before proceeding to describe methods of reducing injuries to restrained children in vehicles, it is necessary to place in context the magnitude of the child road accident victim problem as it exists at present, and how past actions have been reflected in the statistical accident data available.

3.1 National statistics

National statistics for road death and injury in the UK are published annually by HMSO publications. The following analysis (figures 3.1 to 3.12) are based on data taken from Road accidents of Great Britain (RAGB) [3.1], which is a compilation of data returned by police forces (on all injury producing accidents) as part of the STATS 19 system, the road accident data collection process for injury accidents that generally bands children into three 5 year age groups, 0 (birth)-4 years, 5-9 years and 10-14 years. This correlates adequately with the age groups relating to the commercially available infant and child restraint systems, although mass and size are the fundamental guides. Infant carriers/child restraint systems incorporating harnesses (Groups 0, 0+, and 1) are deployed with children up to approx 4 years of age. Booster seats, and booster cushions (Groups 2 and 3) using the adult seat belt are suitable for children from approximately 4 years and older, being used until the child is large enough to be restrained by the adult seat belt alone (7+ years)[1].

3.1.1. Road deaths as a percentage of all deaths in age group

It is appropriate to commence the data analysis by considering road deaths with respect to the mortality rate from all causes for the relevant age groups. Road deaths include all road users, car occupants, pedestrians, cyclists, powered two wheeled vehicle users and bus/truck occupants.

Figure 3.1 shows road deaths of infants[2] and very young children to be numerically lower than for the older age groups but significantly smaller as a percentage of the total mortality (all causes) rate of that group. The percentage of deaths from road accidents is reduced as

[1] CRS types / groups are defined elsewhere in this document
[2] Defined in the statistics as being less than one year of age

a proportion of the overall total by the high infant mortality from natural causes in early life (mortality statistics for England and Wales [3.2]). In the older age groups, child road deaths account for about 20% of the overall mortality rate, whilst for both the younger age groups road deaths as a percentage of the overall mortality rates is reducing slightly.

Total Road Deaths

AGE		Year 1971	1975	1980	1985	1990	1991	1992	1993	1994	1995	1996
0 to 4	Road deaths *	N/A	159	96	90	86	84	66	62	57	54	46
	Total mortality	N/A	12551	10040	8012	7195	*6735*	*5927*	*5613*	*5383*	5144	N/A
	% of total		1.3	1.0	1.1	1.2	1.2	1.1	1.1	1.1	1.0	
5 to 9	Road deaths *	N/A	269	167	166	127	118	75	88	83	68	54
	Total mortality	N/A	1305	969	674	600	*645*	*565*	*515*	*509*	511	N/A
	% of total		20.6	17.2	24.6	21.2	18.3	13.3	17.1	16.3	13.3	
10 to 14	Road deaths *	N/A	196	203	201	155	135	127	120	125	108	111
	Total mortality	N/A	1183	1038	903	652	*631*	*570*	*642*	*586*	606	N/A
	% of total		16.6	19.6	22.3	23.8	21.4	22.3	18.7	21.3	17.8	

* all road users

Note: The 'Total mortality' for 1991-1994 is not available in the RAGB data. The figures for these years are estimated based upon data given in 'The mortality statistics, childhood, infant & perinatal 1995' for England & Wales.

Figure 3.1 Total child road deaths Vs total child mortality

However, more children are injured in road accidents, many seriously, than are killed. Figure 3.2 compare the numbers killed or seriously injured (KSI) with all injuries and shows the scale and pattern of these injuries[3].

Total Killed or Seriously injured on road (KSI)

AGE		Year 1971	1975	1980	1985	1990	1991	1992	1993	1994	1995	1996
0 to 4	KSI on road *	3347	2138	1351	1429	1363	1272	1141	1010	993	968	831
5 to 9	KSI on road *	7120	5150	4203	3579	3217	2658	2588	2166	2457	2186	2208
10 to 14	KSI on road *	5807	5098	5255	4903	3832	3367	3328	3099	3330	3323	3161

Total of All injuries on road

AGE		Year 1971	1975	1980	1985	1990	1991	1992	1993	1994	1995	1996
0 to 4	All road injuries *	N/A	9039	6272	6970	7836	7550	7225	6923	6832	6579	6426
5 to 9	All road injuries *	N/A	21300	16914	14998	16239	14744	14472	13371	14530	13674	14314
10 to 14	All road injuries *	N/A	22083	22742	21676	19778	18277	18694	18591	19664	19222	19603

* all road users

Figure 3.2 Total children KSI/Injured

3.1.2. Type of child road user killed or seriously injured

The type of road user, mainly pedestrian, cyclist, and car user will influence the risk to which a particular age group is exposed. Figure 3.3 shows the distribution of children killed or seriously injured by major class of road user for 1995 and 1996.

[3] These definitions are not classified by AIS values.

Children Killed or seriously injured (KSI) by class of road user (major) and age

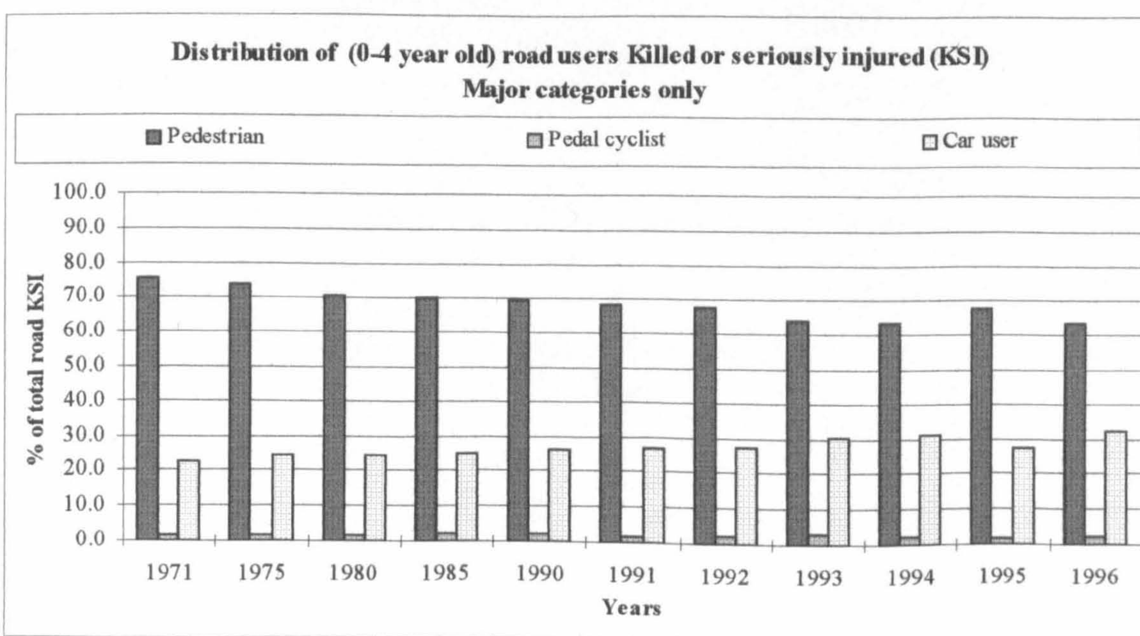
1996	User (Major classes)						
AGE	Pedestrian		Pedal cyclist		Car user		Total *
	N	%	N	%	N	%	N
0 to 4	527	63.4	21	2.5	266	32.0	831
5 to 9	1515	68.6	335	15.2	320	14.5	2208
10 to 14	1811	57.3	719	22.7	462	14.6	3161
% of Total		62.1		17.3		16.9	6200

1995	User (Major classes)						
AGE	Pedestrian		Pedal cyclist		Car user		Total *
	N	%	N	%	N	%	N
0 to 4	655	67.7	19	2.0	265	27.4	968
5 to 9	1500	68.6	335	15.3	317	14.5	2186
10 to 14	1944	58.5	742	22.3	475	14.3	3323
% of Total		63.3		16.9		16.3	6477

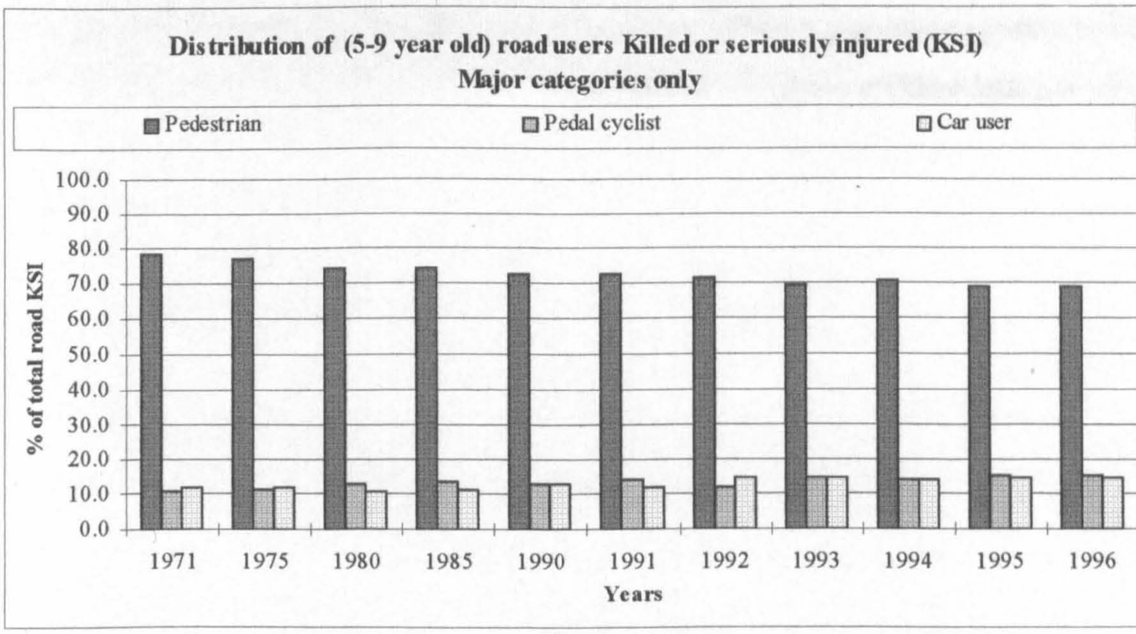
* includes other users, e.g.: motor cycle/moped, Bus/coach and goods vehicle.

Figure 3.3 children KSI by major class of road user

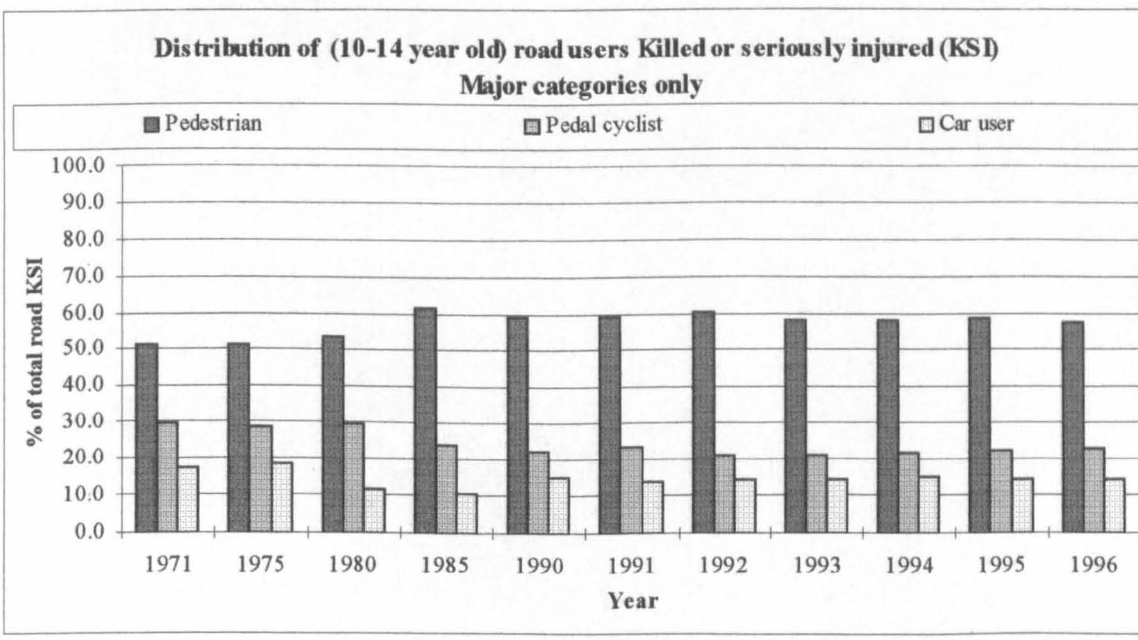
For all age groups the pedestrian suffers the largest number of serious or fatal injuries. For children and infants (0-4 years), after the pedestrian the group most at risk is the car user, with cyclists suffering much fewer injuries. For children aged 5-9 years the cyclist marginally replaces the car user as the category most at risk after the pedestrian and for the oldest group (10-14 years), the cyclist becomes clearly the second most vulnerable risk category, with almost twice the KSI frequency of the car user. This pattern has remained largely unchanged over the last 25+ years (Figures 3.4, 3.5 and 3.6).



Figures 3.4



Figures 3.5



Figures 3.6

With both the 0-4 and 5-9 age groups there is a reduction of the pedestrian injury content with a commensurate increase in the car user, car user/cyclist proportion, reflecting the increasing use of motor vehicles as a means of transport (Figure 3.7).

Population / vehicle usage data

Year	1971	1975	1980	1985	1990	1991	1992	1993	1994	1995	1996
No of licenced private cars x10E6	12.06	13.52	14.77	16.45	19.74	19.74	20.12	20.1	20.48	20.51	21.17
Annual Car traffic x10E10 km	17.56	19.44	22.98	25.05	33.59	33.52	33.64	33.68	34.51	35.32	36.24
UK population x10E6	54.1	54.4	54.4	55.1	55.8	56.1	56.4	56.6	56.8	56.9	N/A

Figure 3.7 Number of vehicles, car miles travelled Vs UK population

The argument that car users in these age groups are suffering a greater exposure to injury is not supported by the evidence. Figure 3.8 shows the number of children killed or seriously injured each year over the period 1971-1994 has been reducing, although since then the overall decline is less evident.

3.1.3. Death and injury of children amongst car users

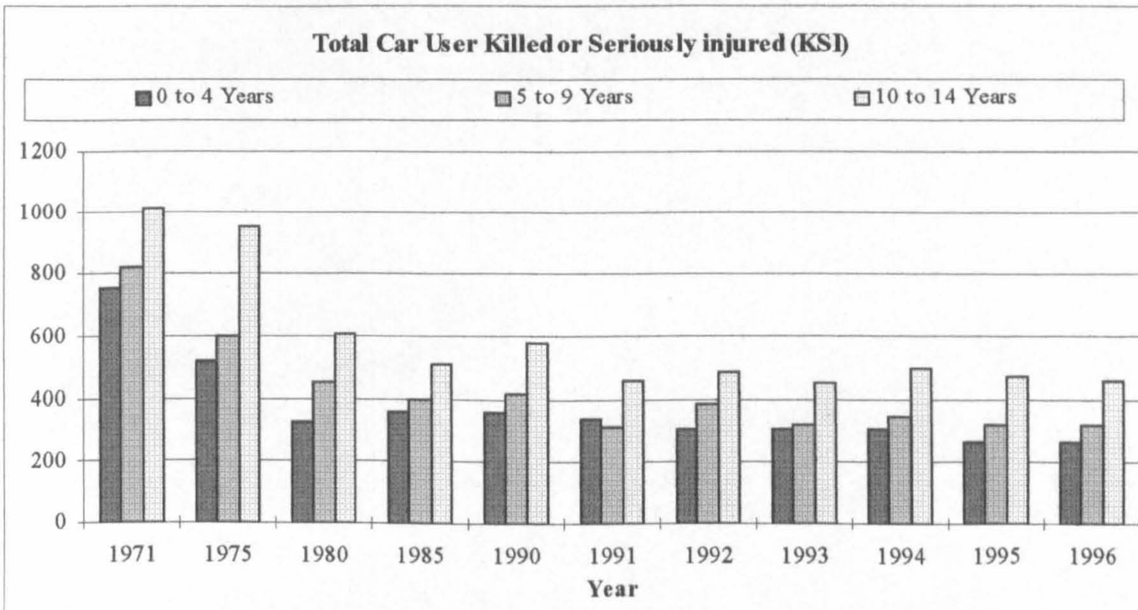


Figure 3.8 Total of child car users KSI by age group

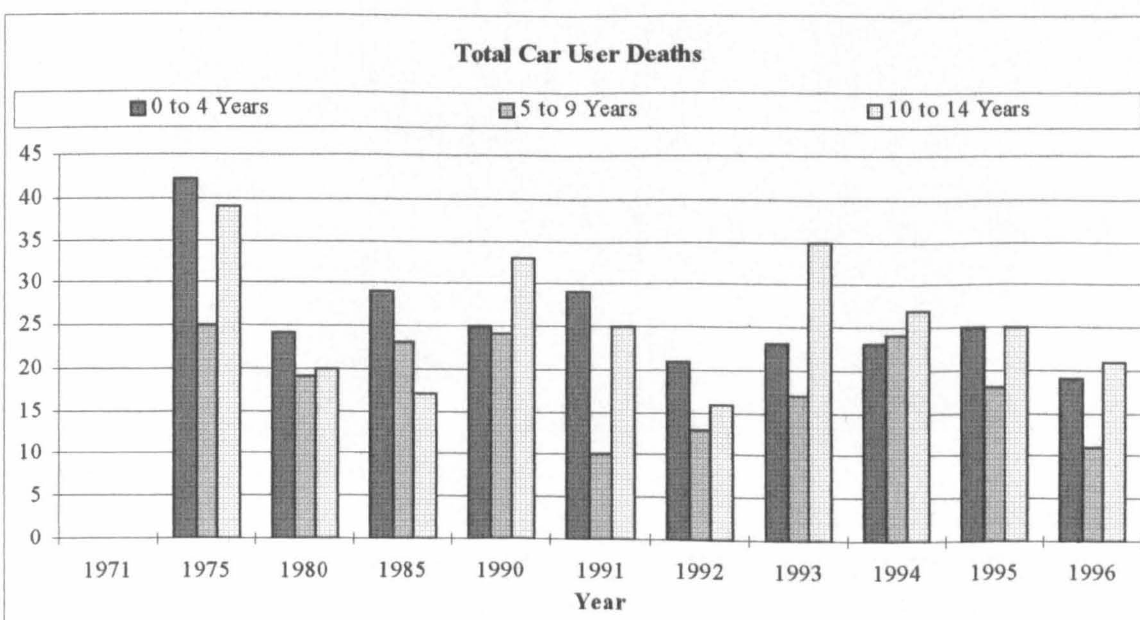


Figure 3.9 Total car user fatalities by age group

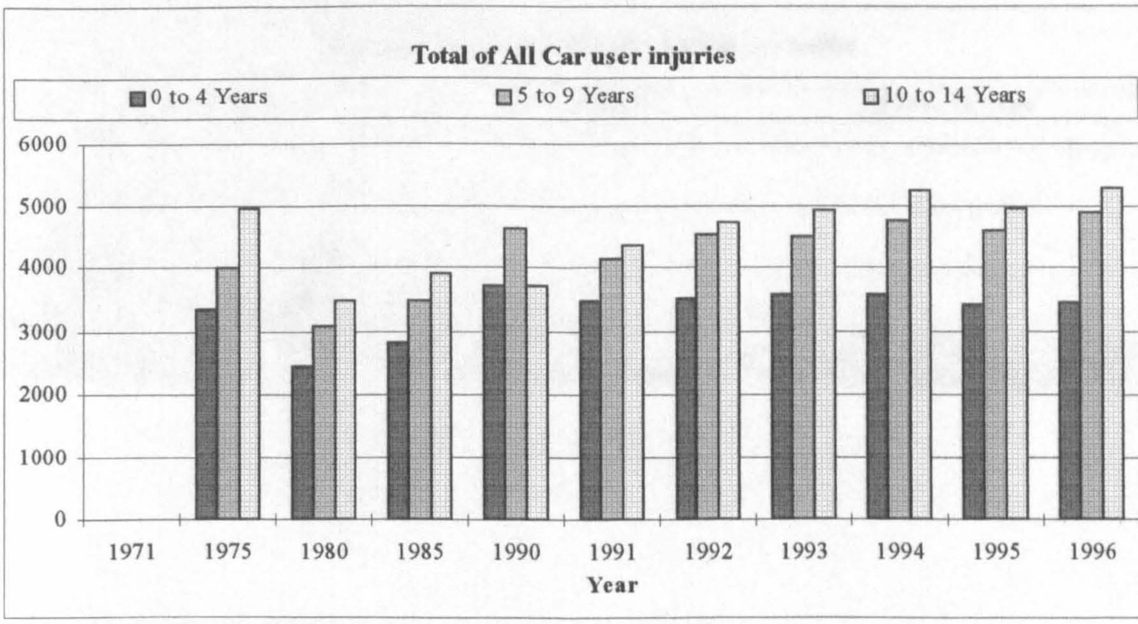


Figure 3.10 Total of all car user injuries by age group

The data for all injuries suggests a slight increase in recent years, although when weighted against the increase in road traffic the rise is less noticeable (Figures 3.11 and 3.12)

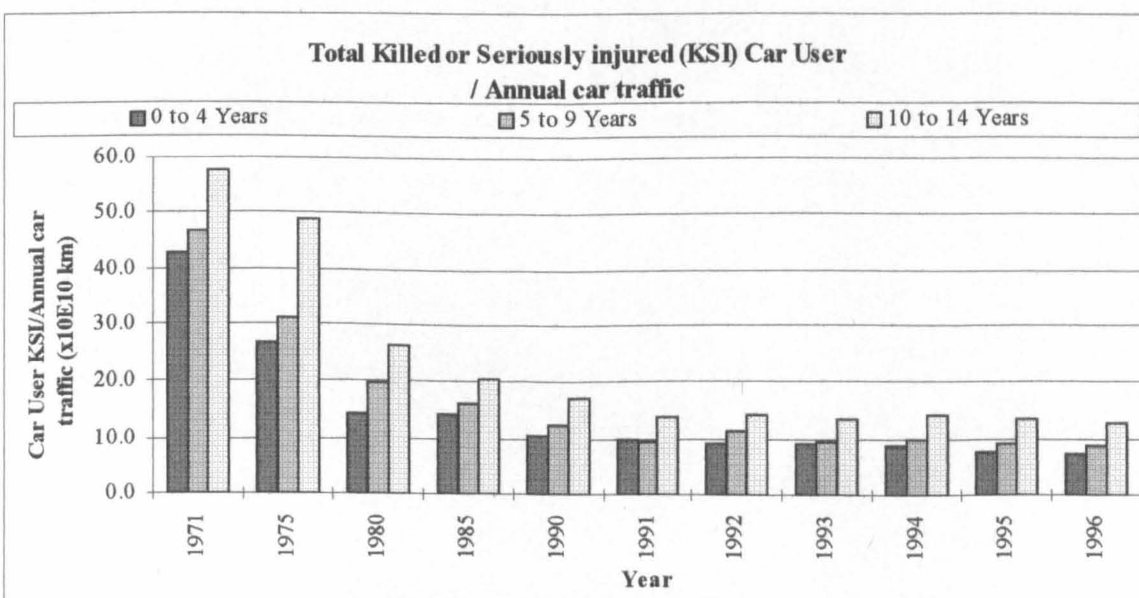


Figure 3.11 Total of car users KSI weighed against annual traffic mileage.

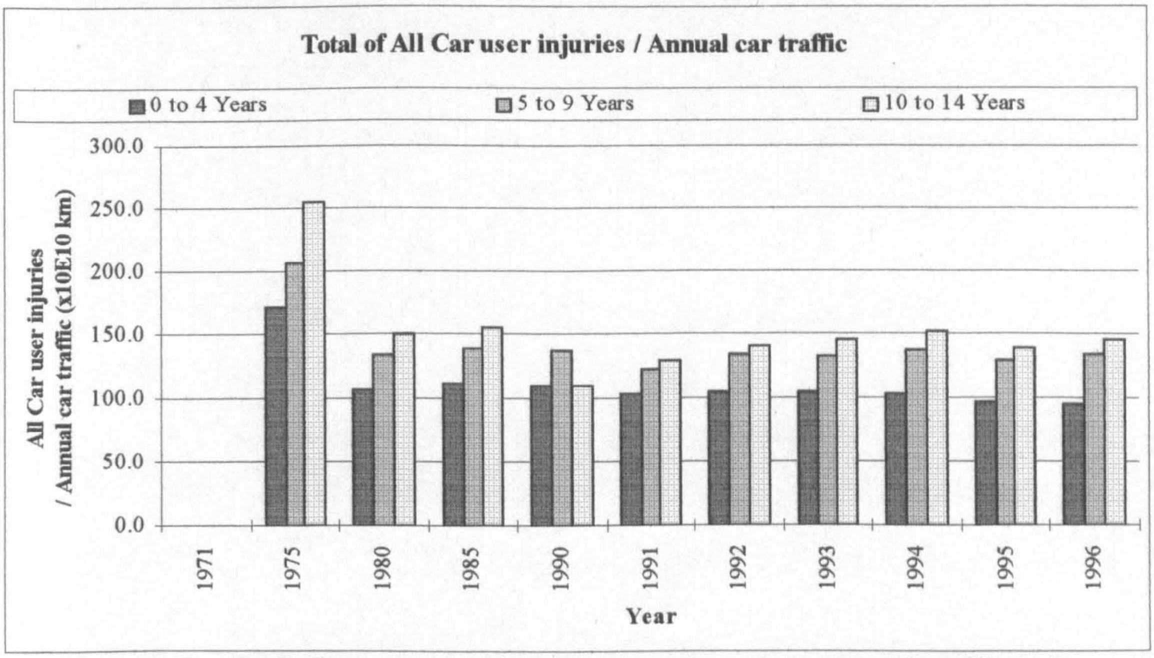


Figure 3.12 Total of all car users injured weighed against annual traffic mileage.

Figures 3.11 and 3.12 show that for car users serious/fatal injuries to children (0-4 years) continue a slow decline when evaluated against the increase in vehicle traffic. For older children (5-9 and 10-14 years) the reduction of those exposed to serious injury has been less evident over recent years. It is for the 0-4 year group that most CRS development has occurred, and continues. Further, section 3.4 will show a greater usage of restraints by this age group than for the older (5-9 and 10-14 year) groups.

3.2 Legislative events relating to child occupants of vehicles

Significant legislative events with respect to vehicle, child passengers, and occupant restraint are shown below for the period relating to the above data.

1966-1967	Adult seat belts made compulsory in new cars.
1983	The wearing of seat belts made compulsory for car drivers and front seat passengers.
1987	All new cars to be fitted with rear seat belts or child restraints.
1989	Seat belt wearing by rear child passengers becomes compulsory in cars where appropriate restraints have been fitted and are available.
1991	Seat belt wearing by rear adult passengers becomes compulsory in cars where appropriate restraints have been fitted and are available.

In addition activities such as periodic safety campaigns may have influenced the statistics, however an inference that could be drawn from figures 3.11 and 3.12 is that child restraint legislation (compulsory requirement) has only had a minimal effect on overall car user injuries with a slight reduction noticeable in those killed or seriously injured.

3.2.1. Current UK Legislative Position regarding use of CRS

Figure 3.13 summarises current UK legislation (Road Traffic Act 1988 [3.3]) and (Statutory Instruments 1993 Nos. 31 [3.4] and 176 [3.5]), regarding the transportation of children in vehicles, according to occupant age, seating position and the use of CRS.

Occupant	Front seating position	Rear seating position
0-2 (inclusive) years old	An appropriate CRS must be used	An appropriate CRS must be used if available
3-11 (inclusive) years old and under 1.5 m in height	An appropriate CRS must be used if available, if not an adult belt must be used	An appropriate CRS must be used if available, if not an adult belt must be used if available
12/13 (inclusive) year old or over 1.5 m in height	An adult belt must be used if available	An adult belt must be used if available
14 + years (adult)	An adult belt must be used if available	An adult belt must be used if available

Figure 3.13. Legal requirements relating to CRS usage in the UK

These regulations do not require very young children in the rear seating position to be restrained if no CRS is available, thus exposing them to the risk of ejection. Further, the regulations could be interpreted to imply a road traffic offence, if a very young child (under 3 years of age) was restrained in the front seat by an adult belt, even if there were no belts in the rear. This is because the adult belt alone is considered unsuitable as a child restraint for that age group. It should be noted that booster seats can, and are approved for children of mass 9 kg (9 months old) upwards under ECE Regulation No 44.

3.3. Seating Position within the Vehicle

The occupant seating position within a vehicle should be considered significant when assessing the safety of occupants. A study by Rattenbury and Gloyns of restrained child fatalities (1979-1991) [3.6] highlights the significance of intrusion as a factor in occupant injury (the proportion of fatalities involving intrusion is indicated in section 3.6.1 of this chapter). The importance, therefore, of an optimal seating position with respect to potential intrusions cannot be ignored. Roy [3.7] reported that the seating position with the least frequency of intrusion in a sample of high energy input accidents was the centre rear, the front passenger seat having 3.6 times the frequency at the dashboard level (the level of the child's head).

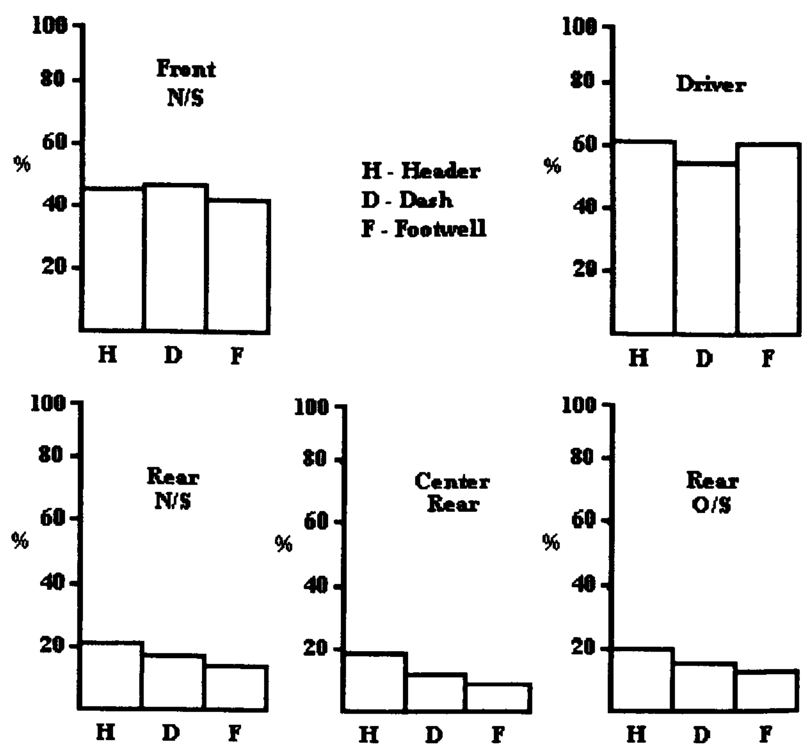


Figure 3.14 Seating position with respect to frequency of intrusion N=229 UK vehicles [3.7].

In North America Braver et al [3.8] investigated the inter-action between seating position, impact type/direction, vehicle speed, vehicle size, occupant restraint usage and air bag equipment for children aged 12 years and less.

One of the results of this study was that children benefit from rear seating, particularly in passenger cars, except for the case of rear impact, although the study reported relatively few fatal passenger car rear impact collisions, (this US study reported only 5%, whilst

Rattenbury and Gloyns in the UK indicates a slightly higher figure for fatal rear impacts (16% for CRS and 8% for adult belted child occupants)). The benefit of rear seating was found to be not statistically significant for midsize utility vehicles, station wagons and mini vans.

The US study also suggested that children in the rear centre seat have a lower risk of dying when involved in fatal crashes than child occupants of rear outboard seats.

The centre rear seat position, whilst being the optimum in terms of distance from any intruding vehicle in a collision (other than a rear impact), is compromised because in many cases it is equipped with a lap belt, not the preferred lap and diagonal belt[1].

The air bag issue has become a concern in recent years, mainly in the USA and to a lesser extent in Europe. Studies and incidents have demonstrated that children should <u>never</u> be placed in rear facing child restraints in the front seating position of vehicles equipped with a front passenger air bag. A rear facing infant carrier is too close to the vehicle instrument panel resulting in it being struck by the deploying passenger air bag (mean upper surface velocity of a deploying air bag can be in the order of 160 km/h). The loads involved are often sufficient to severely or fatally injure a child. This concern is not confined only to infants, but potentially to any <u>out of position</u> occupant, child or adult.

3.4. CRS Usage and Misuse

The effectiveness of any CRS may be significantly compromised by faulty installation. This section considers current and historical usage rates of restraints and discusses the question of misuse.

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[1] Furthermore, it has been suggested that, in the case of lone adults transporting infants, it is desirable for the driver to keep the child within eye contact. It has been surmised, although not proven, that a number of collisions have resulted from the driver turning to attend to a child in a rear seating position [3.7].

3.4.1. CRS Usage Rates

Restraint use by both adult and child occupants of vehicles has risen notably in the last 25 years, reinforced by mandatory usage requirements. Figure 3.15 summarises CRS usage rates in the UK (TRL [3.9. 1974] [3.10. 1982-1986] [3.11. 1991-93]). Although the data is not in comparable format, it is possible to infer an upward trend in usage rates for restraints amongst the child population.

Survey Year	% Restrained, Seat position: front	% Restrained, Seat position: rear	Child age
1974	17%		0.5-4 years
November 1982	0%	30%	< 1 year
	12%	40%	1-4 years
June 1983	5%	46%	< 1 year
	66%	27%	1-4 years
November 1984	0%	49%	< 1 year
	60%	34%	1-4 years
June 1986	45%	55%	< 1 year
	47%	42%	1-4 years

Survey Year	% Restrained, Seat position: front	% Restrained, Seat position: rear	Child age
October 1991	94%		0-13 years
		86%	< 1 year
		88%	1-4 years
		71%	5-9 years
April 1992	94%		0-13 years
		91%	< 1 year
		83%	1-4 years
		69%	5-9 years
October 1992	93%		0-13 years
		86%	< 1 year
		84%	1-4 years
		65%	5-9 years
April 1993	93%		0-13 years
		89%	< 1 year
		88%	1-4 years
		71%	5-9 years

Figure 3.15. CRS Usage Rates

These data indicate increased use of CRS in recent years, but this inference must be interpreted with caution because some of the sample sizes are small. However, particularly since introduction of mandatory usage requirements, CRS employment in the 0-4 year old group has increased towards the region of 90% usage rate (US studies put the rate at 75% [3.12], and 81-96% depending on child age [3.13]). It is worth noting the lower UK usage rate of about 70% for older children (>5 years old) in rear seating positions when using the adult belt as the primary restraining medium.

CRS usage rates can be affected by factors such as age of the child, income/education level of the family and behaviour with respect to health matters, however it would appear from the above data that in the UK drivers/carers have now been persuaded that CRS usage is required/beneficial when transporting children, and that to a large extent they are willing to employ such devices, particularly for the younger child.

Although restraint usage by children, especially the younger child, is high, the effectiveness of such devices can be compromised if they are wrongly installed or not used as intended. It is important therefore to review both these contingencies.

3.4.2. CRS Misuse

UK CRS misuse survey rates are potentially unreliable due to effective 'subject self selection', (BBC Watchdog 1990), and/or have been confined to selective parts of the country, (Dorn M, Middlesex University/Bedfordshire County Council, 1991 [3.14], Devon County Council reported here). There is no source for unbiased national data. The most recent study, is that conducted by Devon County Council [3.15] biannually as part of the 'Fit Safe Sit Safe' campaign started in 1995 backed by the Child Accident Prevention Trust. This survey is based on a series of supermarket site assessments (accompanied by fitting guidance/instruction from council staff) across the county, however it must be stressed that attendance was in response to local press advertising, hence 'self selection' by subjects. In the three year period to 1998 the survey has involved checks of over 1500 CRS. However to include as large a sample as possible of CRS certified to the latest ECE R44 03 standard only the latest data (September 1998) is presented below, comprising of 397 examinations. To classify overall deficiency rates, the study addressed the origin (new or pre-owned) of the CRS (This report is as yet unpublished).

Devon County Council 'Fit Safe Sit Safe' CRS survey (September 1998)

CRS may be misused or mis-installed in a variety of ways, the more common being : Incompatibility with the age of the occupant, installation in the wrong direction (rear facing devices), installation in the wrong position (incompatibility of Group 0 rear facing devices with front seat air bags), damage or poor condition, improvised fixing to vehicle, incorrect adult belt routing, loose installation, buckle interference with CRS frame (buckle crunching), poor/incorrect CRS harness adjustment. Figure 3.16 shows the deficiency rate for the CRS examined.

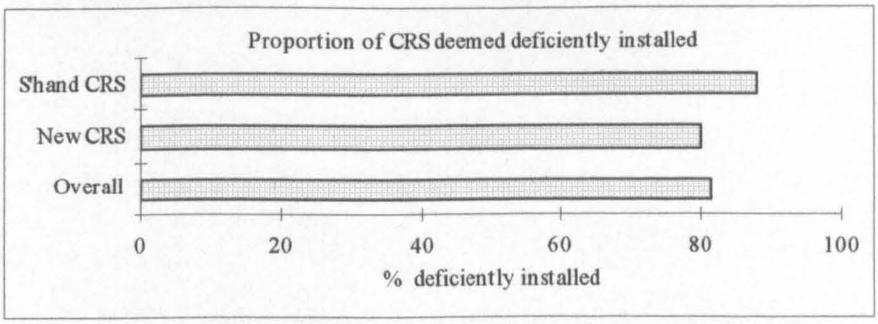


Figure 3.16 Proportion of CRS deemed deficiently installed in Devon survey

The failure rate for the 'pre-owned' CRS is shown to be slightly higher than the overall rate at 87.9% compared with 81.3%, however the sample size was small in comparison, 17% (N=66) to the total assessed.

Discussion of misuse

Compared with the earlier UK study (Dorn 1992) the calculated overall misuse rate although slightly higher in 1998 (81%) than in 1992 (77%) it is of a similar order (the sample size in the 1992 study was considerably smaller with only 61 observations). This latest assessment of UK mis-use rate would appear to be greater than presented in a recent European study (Hummel et al 1997 [3.16]) indicating a 63% misuse rate from a sample of 250 observations. Another recently reported study from Michigan USA [3.12] indicates an overall misuse rate of 89% from a smaller sample of 87. A larger 1996 [3.17] US study conducted by NHTSA, of over 4000 vehicles in four states suggested a misuse rate of 80%. Although these studies may not necessarily be directly comparable, they do indicate an appreciable level of misuse in practice.

A closer examination of the recent UK study [3.15] shows that the types of CRS causing the greatest concern are the Group 1, Group 0/1, and Group 0 devices. These types generally require the adult belt to be threaded along a unique path through the mounting attachments or frame before being tensioned and locked off to secure the device to the vehicle seat. (Since over fifty percent of the 66 'pre-owned' devices were of the Group 1 type, only Group 1 'pre-owned' items have been represented in figure 3.17).

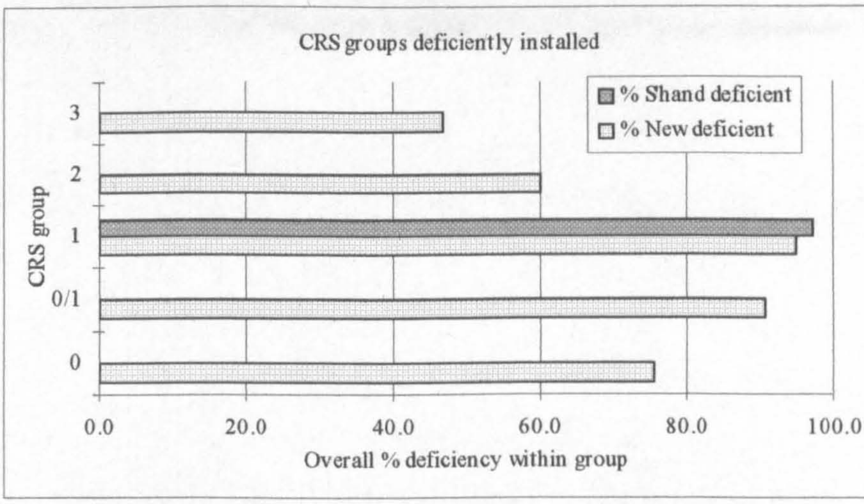


Figure 3.17 Misuse as a function of CRS group/type

The principal area of concern relating to CRS is the interface with the vehicle, mainly due to loose fitting, followed by buckle interference, and wrong routing of the adult belt (see figure 3.18). Each of these concerns are overcome if the adult belt interface is replaced by rigid dedicated fixings. This is the Isofix concept.

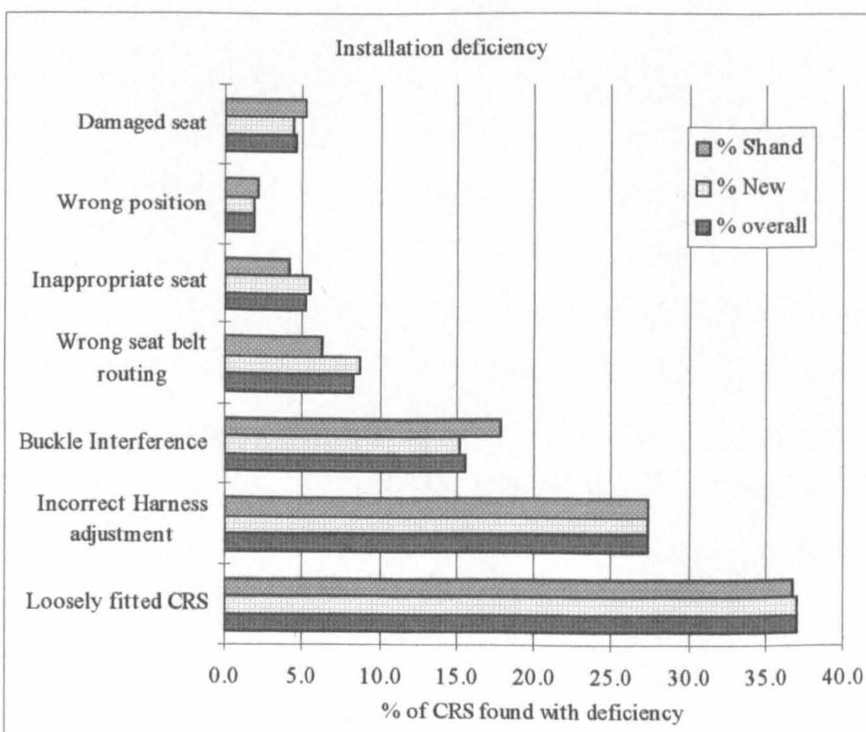


Figure 3.18 Frequency of Misuse type

The Devon study also highlighted inappropriate or damaged CRS, wrong seating position, and concerns with respect to harness adjustment. The two former items are potentially only resolved by education, however the harness adjustment issue is more difficult to address. The latest European test standard ECE R44 03 specifies a harness adjustment load of 250

±50 N over and above the static load of the adjuster for certification test purposes. In principle, children should be installed in the restraint as tightly as possible, however in practice this can prove difficult. A factor influencing this is thickness of clothing which can vary with the climate. The effect of thickness of clothing on performance of Group 1 forward facing CRS is considered elsewhere in this document (Chapter 10).

Damaged or incomplete CRS (including loss of instructions) are often cited as potential dangers with pre-owned restraints. However this argument does not appear to be supported by the Devon data reviewed, which recorded a higher rate of 'damaged' seats of only 1% whilst buckle interference was 3% higher. However misuse due to wrong belt routing and loose CRS installation were respectively 3% and 0.3% lower. Since belt routing, tightness and buckle location are all specified in the instructions, and the above differences are small, concerns with respect to pre-owned CRS do not appear to be evident in this data. (However it should be noted that the Devon study does not reflect the severity of any misuse observed)

An important point not directly recorded in the observed data (other than that 'buckle crunching' was observed) was the length of rear seat buckle stalks in some vehicles. Older vehicles in particular employ buckle stalks too long even for the latest ECE R44 03 approved Group 1 forward facing CRS (R44 03 requires a minimum 150 mm to the load bearing point on the CRS frame). In these vehicles it proved impossible to satisfactorily install the CRS with the approved belt routing. Some newer R44 03 framed products have instructions detailing an alternative routing that effectively place the buckle underneath the CRS. However, although complying with the dynamic requirements of the standard, these alternative routings can't be approved to the standard due to the 150 mm requirement. Since this alternative routing is the only method to achieve an acceptable installation in many vehicles, a suitable alternative routing should be mandatory on all 'universal' CRS.

Finally due to the geographic location of the recent study it is worth comparing the data from the latest Devon study conducted during the month of September with the figures from a similar study conducted 6 months earlier, in March 1998. The overall CRS failure rate for this earlier 1998 study at 87% compared with the rate in the latest study of 81% would tend to suggest that any seasonal effect (Devon is a UK holiday area) is not of great significance.

Summary of misuse

Misuse of CRS may result in reduced performance and hence increased risk of exposure to injury for the occupant. The dangers of CRS that are damaged/in poor condition or are attached by defective adult belts is self evident, as are the potential ramifications of improvised fixings. However such deficiencies are shown in the above study to be few in number. The more common concerns, of loose installation, incorrect belt routing or buckle interference all have the potential for, at best degraded performance as a result of excessive head excursion or at worst, complete failure due to CRS detachment. The influence of intrusion as a major factor in restrained child fatalities has been shown by Rattenbury & Gloyns 1993 [3.6] (also evident in data in a preceding study of restrained child fatalities. Lowne et al 1987 [3.18]). It is an essential requirement of CRS design to minimise the potential for head contact with any part of the vehicle (including the potential for intrusion) and to this end the proposed Isofix CRS/vehicle interface is intended to address many of the above miss-installation concerns.

The introduction of Isofix is intended to eliminate problems of miss-installation and enhance dynamic performance. However Isofix itself has unique installation concerns. Conventional CRS poorly installed with slack and incorrect belt routing may not perform optimally, but may still function and preventing ejection. On the other hand an Isofix CRS which has not been securely latched has the potential to be completely ejected from the vehicle. To eliminate this possibility, it is essential to ensure latch attachments are secure and with fool proof fitting.

3.5. Impact Type/Direction

The type of impact to a vehicle and the direction of impact will significantly influence the effectiveness of a restraint system. Primarily restraint systems in vehicles are designed to mitigate injuries due to impacts with a major frontal component since the majority of accidents are of this type.

Impact types in the general accident population

A study in the early 1970's (Mackay G .M et al [3.19]) indicated the following distribution of impact areas for vehicles in the UK.

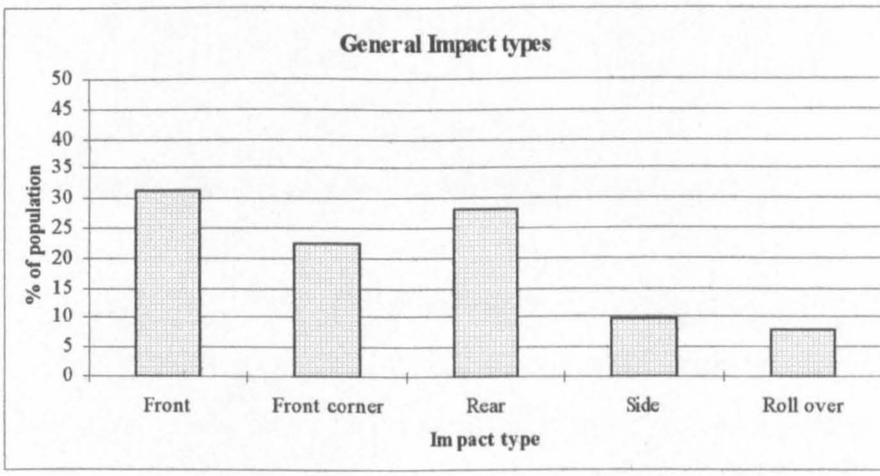


Figure 3.19 General Impact distribution UK

Impacts in the front or front corner accounted for in excess of 50% of all impacts. Rear impacts between 25% and 30%, whilst side impacts accounted for only around 10%. Other types of impact such as roll over accounted for the remainder.

The general distribution of this UK data is supported by German research (Langwieder and Hummel (1989) [3.20]) using a postal questionnaire of respondents to press articles on road accidents involving child occupants, restrained and unrestrained. The sample covered all injury severity (MAIS 0 to MAIS 6) in a range of accident impact severity. This study reported the distribution of the main impact areas on the cars with child occupants to be front (including front corner) 51%, rear 23%, left hand side 14%, right hand side 10% and roll over 2%. Side impact in this study was slightly higher than in the earlier UK study whilst rear impact and roll over were slightly lower.

Impact types in child fatality cases

Data for restrained child facilities in the UK (Rattenbury and Gloyns [3.6]) shows a significantly different distribution pattern of impact type (see figures 3.20 and 3.21).

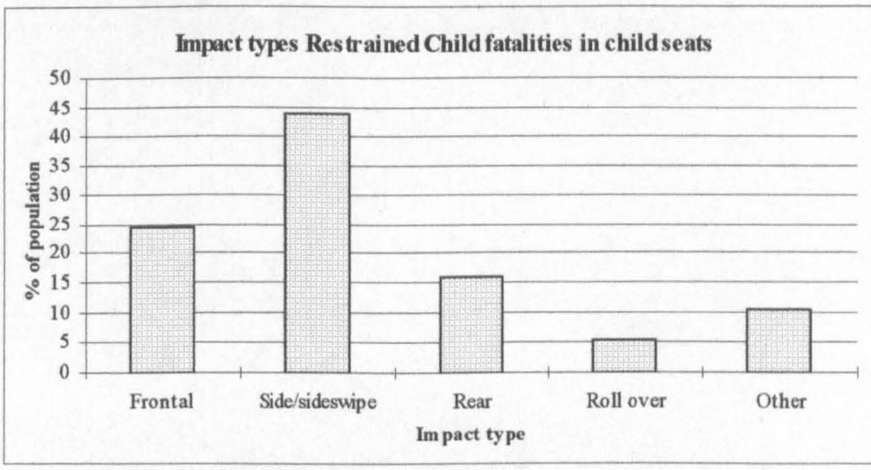


Figure 3.20 Fatalities using child restraints (N=57)

Side impacts or side impacts with a frontal component comprise the majority (44%), followed by frontal (25%) then rear impacts (16%). In this analysis the seating position within the vehicle was predominantly a rear seat (88%) and that the age group was primarily <36 months.

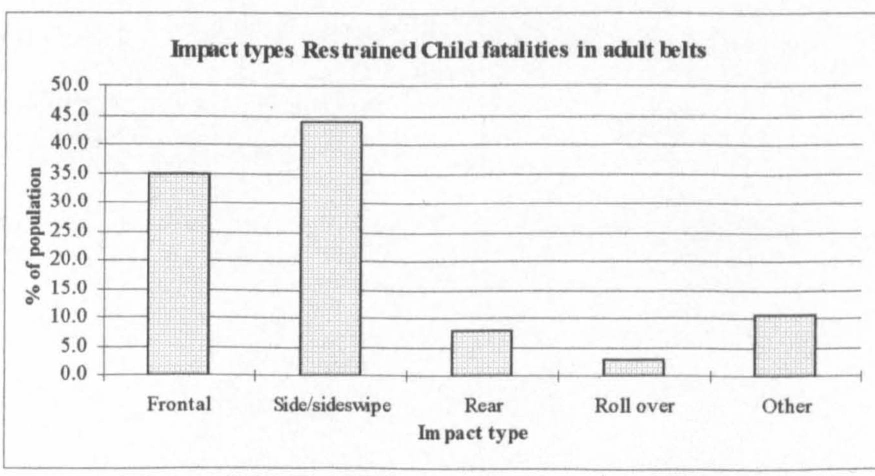


Figure 3.21 Fatalities using adult belts (N=66)

Again side impacts or side impacts with a frontal component were the majority (44%), followed by frontal (35%) and rear impacts (8%). This time the seating positions in the vehicle were mainly the front seat (64%) and the age group was primarily 5-14 years.

In this study there were only six children using booster seats/cushions with adult belts and all the impacts were side impacts or side swipes.

Further there were only seven younger children in infant carriers and of these six were severe frontal impacts, the other a side swipe. It was been suggested that incorrect adult belt routing and rear loading caused by unrestrained rear seated adults contributed to a number of these fatalities.

The German study reported that for both unrestrained and restrained children serious or critical injuries occurred only in the head on impacts or side collisions with lower frequency for restrained children.

From the UK fatality study [3.6] it is evident that side impacts with the possibility for severe intrusion are major causes of child fatalities. Others, [3.20] have confirmed this general conclusion.

The vehicle, restraint and occupant interface is crucial for all round optimum performance of the restraint system. Performance, however, is significantly affected by the direction of impact and to side impacts in particular because :

- of the restricted energy absorbing zone in the vehicle side structure and the potential for direct head and torso contact;

- restraint systems are not designed to perform in side loading although they should prevent ejection from the vehicle;

- The human frame is less well suited to being restrained in a lateral direction than in the fore aft direction.

3.6. Nature of Fatal Child Injuries

It is appropriate at this point to review available accident data to establish the nature of injuries sustained by child occupants of cars, to infer the effectiveness of restraint systems and facilitate future improvements to both products and acceptance standards.

The disadvantage of this type of restraint performance assessment is the time lag before the accumulated number of accidents involving a particular restraint/restraint feature becomes statistically valid. Furthermore, the number of seriously or fatally injured child occupants is relatively small (See figures 3.8 and 3.9). Not only is the data limited in size, but the time lag may limit the value of this information to systems under continuous development. For example, restrained child beds (carry cots) for infants (Group 0) were at one time popular, but have now almost entirely been superseded by rear facing infant carriers. Similarly forward facing four point (dedicated straps) CRS for the older (Group 1) child have been almost completely replaced by framed CRS employing the now much more widely available rear seat adult belt system to affix them to the vehicle. Such an evolutionary process has developed the first Isofix restraints along with improved conventional belt retained restraints.

The more current the accident data the more valid is its contribution to CRS and acceptance standard development.

3.6.1 Child accident injuries in the UK

The annual UK casualty report (Department of Transport 'Road accidents of Great Britain') does not detail the type or nature of injuries sustained by child casualties although the most recent national accident study (Rattenbury and Gloyns [3.6]) reviews restrained child fatalities between 1979 and 1991 using the stats 19 database. Due to the increase in restraint usage (see figure 3.15), no recent documented work relating to unrestrained children in the UK has been found. However Roy (1980) [3.7] observed that for both restrained and unrestrained child vehicle occupants, the head and face had the highest frequency of injury and also the highest frequency of fatal injuries. It was also noted that for unrestrained children, both the proportion injured and the proportion with life threatening injuries increased with age.

From the fatally injured accident study by Rattenbury and Gloyns of restrained children under the age of 14 years, the distribution of injuries in relevant restraint types was reported as follows.

Rear facing infant carriers (N=7) : Six of these cases were severe frontal accidents the seventh being an angled side impact with severe intrusion, all the victims suffered head injury and lung contusion in addition to rib fractures in one case and serious internal abdominal injures in two others. Poor installation with respect to adult belt routing and loading from unrestrained rear seat passengers was highlighted as of concern in the majority of these cases.

Forward facing child seats (N=57) : In this category 25% were frontal, 44% side/sideswipe and 16% rear impacts. Head injury was evident in 18 of the 20 side impacts, and in all 5 side swipes the majority of which involved severe intrusion, Four of the 14

frontal impacts involved high levels of intrusion causing fatal head injuries, whilst one other head/face injury was attributed to possible contact with the back of the drivers seat. One further head injury in a severe frontal impact appeared to be as a result of a non contact head rotation. Neck injury was evident in six of the frontal impact cases as a result of either excessive flexion (due to poor CRS anchoring) or as a result of submarining. In side impact life threatening neck injury was evident in only in two cases. Chest/abdominal injuries were evident in only one of the frontal impacts, due to ejection, whilst in the side impacts 8 sustained life threatening chest and one sustained life threatening abdominal injuries. In rear impacts, head injuries predominated as the cause of death (mainly from intrusion) in addition to some neck and chest injuries.
In the remainder of the impact scenarios, multiple, complex and rollover 5 of the 7 cases involved severe intrusion causing life threatening head injury.

Adult belt with booster seat or cushion : All six cases were side impacts/sideswipes with major intrusion. Four of the cases featured the existence of life threatening neck injury, the cause of which was unclear.

Adult belt only : There were 66 cases and of these 35% were frontal impacts, 44% side/sideswipe with only 8% rear impacts. Of the frontal impact cases, 78% involved intrusion, with 17 life threatening head impact injuries. Interestingly of the four cases of neck injury the youngest, a 3 year old appeared to have sustained the injury from the adult belt (this was the only evidence of belt induced neck injury). Life threatening chest, and abdominal injuries were also evident in moderate numbers. In the 25 side impacts there were 13 life threatening chest injuries and 13 life threatening head injuries. In addition to 10 life threatening abdominal injuries, with 5 life threatening neck injury. Intrusion into the occupant seating position was evident in 68% of the cases.

3.6.2 Injuries outside the UK

In the 1988 German study (Langwieder and Hummel [3.20]) the body area injury frequency for unrestrained children in frontal impacts (N=67 children) was the head 61%, arms 21%, legs 16%, chest 10%, shoulder 9%, neck 6%, abdomen/pelvis 5%. The large majority of these injuries were minor (AIS1) but there were a few more serious injuries (AIS3 and above) to the head, abdomen/pelvis and arm.

Of those unrestrained in side impacts (N= 27 children), the body area injury frequency was head 56%, legs 44%, arms 37%, shoulder 11%, chest 7% and 4% to both abdomen/pelvis and neck. Again the large majority of those injuries were minor (AIS1), although there were some severe injuries (AIS3 and above), to head and abdomen/pelvis area.
In the analysis of restrained children in frontal impacts (N= 77 children), the body part injury frequency was head 65%, abdomen/pelvis 16%, chest 13%, arms, legs and neck 8%, shoulder 7%. Again, there were very few serious injuries (AIS3 and above), these related to neck and abdomen/pelvis areas. For restrained children in side impacts (a much smaller sample N= 24 children), the body part injury frequency was head 58%, neck 25%, arms 17%, shoulder 17%, abdomen/pelvis 13%, chest/legs 8%. Again the more serious injuries were to the head, neck and abdomen/pelvis areas.

It is clear, therefore, that the head is the most vulnerable part of the body for both unrestrained and restrained children, and that from the injury numbers, the proportion of serious head injuries (AIS 2-6) was significantly greater for unrestrained children.

Both the UK and German studies are dated and do not reflect the performance of the latest child restraints, nor the benefits afforded by modern vehicle safety features. In addition restraint types do vary between countries. For instance in Germany, shield type Group 1 restraints are more common than in the UK.

Summary of injury data

The frequency and scale of injuries to restrained occupants will depend to a large extent on the type and severity of impact. However the studies above confirm the head to be the most vulnerable area of the body, with chest, abdomen and neck also proving exposed. Particularly undesirable are impacts with major intrusion into the occupants seating or safe ride down area, which can result in direct contacts with either the interior components of the target vehicle, or with parts of the intruding vehicle. Side impacts pose a particular concern, due not only to the potential for intrusion, but also the lack of energy absorption zone on the struck vehicle and undesirable restraint loading configuration.

4. VEHICLE DESIGN AND IMPACT TYPE

Vehicle design is a major factor in the occupant safety system. The vehicle comprises a strong protective cage with energy absorbing systems to the front and rear. The cage protects the occupants from direct contacts and in a frontal/rear impact the energy absorption system allows the cage and occupants to be accelerated/decelerated within tolerable limits.

In road accidents, vehicles impact with each other or with stationary objects in a variety of directions (see chapter 3) although frontal impacts (distributed, offset and oblique) are the most frequent type. For this reason safety legislation and vehicle design have in the past been concerned primarily with such impacts.

4.1. Vehicle Type Approval

4.1.1. Distributed frontal impact

Until 1998 the frontal impact acceptance test for type approval of new cars in the UK (ECE R12 [4.1]) in force since 1969, was based upon a 30 mph (48 km/h) distributed impact with a rigid (non deformable) barrier. The acceptance criteria was based upon translation of the steering wheel horizontally and vertically within the vehicle.

4.1.2. Off-set frontal impact

However, only of the order of 30% of accidents tend to be truly frontal (see figure 3.19), almost as many (22%) are concentrated to one front corner, typical is the overtaking (overlap impact) type of accident shown in figure 4.1.

Figure 4.1 Off-set frontal impact[1]

The impact energy in this type of impact is concentrated on one side of the vehicle only. (Note the deformation of the roof, indicating deformation/intrusion of the safety cell leading to a greater potential for occupant contact with the interior).

[1] Photograph courtesy of TRL

In September 1998 a revised type approval test [4.2] for new vehicles was to be introduced, consisting of an offset impact with a deformable barrier (to simulate another vehicle) as shown in figure 4.1 at a more realistic 56 km/h (35 mph).

4.1.3. Side impact

Type approval requirements for side impact protection [4.3] were also introduced in September 1998. This test comprises a perpendicular distributed collision at 50 km/h with the side of the vehicle by a trolley fitted with deformable impactor to simulate contact with another 'standard' vehicle. Figure 4.2 shows the type of impact in plan view.

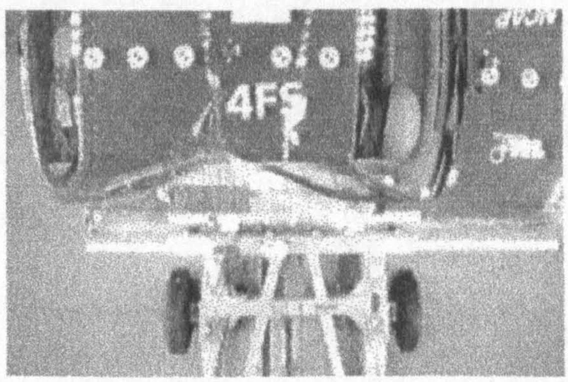


Figure 4.2 Perpendicular side impact with deformable impactor[1]

4.1.4. Rear impact

There is no vehicle type approval test for rear impact with respect to occupant impact protection. (There is however a distributed rear impact test with respect to fuel tank integrity)

4.2. Vehicle Design with respect to impact protection

The importance of integrating vehicle and restraint system cannot be over stated. The vehicle structures and the safety cage in particular are designed, in the event of an accident, to mitigate the effect of intrusions whilst restraints, in conjunction with the vehicle crumple zones are designed to minimise occupant decelerations and limit forward movement during the impacts.

[1] Photograph courtesy of TRL

The modern motor vehicle consists of 3 integrated structures, a passenger compartment comprising the safety cage with energy absorbing front and rear crumple zones designed to protect the occupants from impacts with major frontal or rear components (see figure 4.3.).

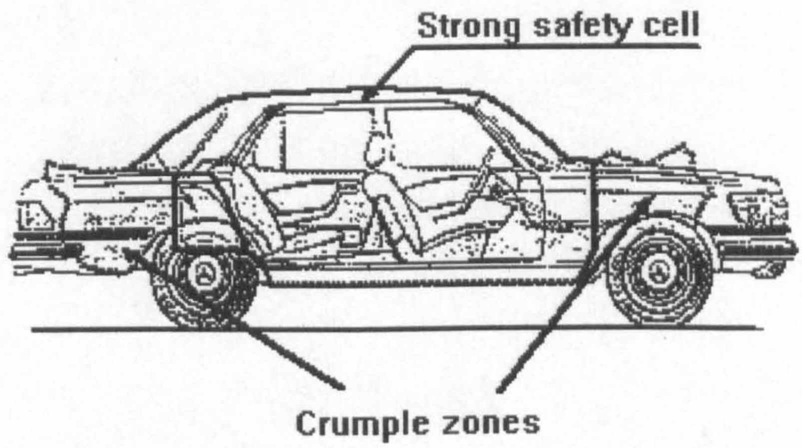


Figure 4.3 Vehicle safety cell and energy absorbing structure [4.4]

4.2.1 Frontal Impacts

When a vehicle impacts a solid unyielding object, for instance a large fixed concrete block, it decelerates in a manner controlled by the way the front end of the vehicle crumples or deforms. It is the way the frontal zone of the vehicle is engineered to deform that dictates the deceleration pulse experienced by the rigid passenger compartment. The greater the distance in which the passenger compartment has to stop the lower the deceleration it will experience assuming the collapse can be controlled in a constant manner.

Ideally this process is progressive so that the deceleration pulse experienced by the occupant compartment is constant and hence minimal (see figure 4.4), and that the deformation is plastic, not elastic, ensuring maximum energy absorption without rebound of the passenger cell, therefore producing a minimal overall occupant velocity change.

Figure 4.4 shows the ideal (constant) passenger cell pulse, and the less desirable saw tooth and 1/2 sine wave pulses. In real accidents, due to engineering limitations (such as solid engines) the collapse of the crumple zone is not perfectly progressive, but although actual pulses may not be ideal, deceleration rates are designed to approximate a constant in most modern vehicles.

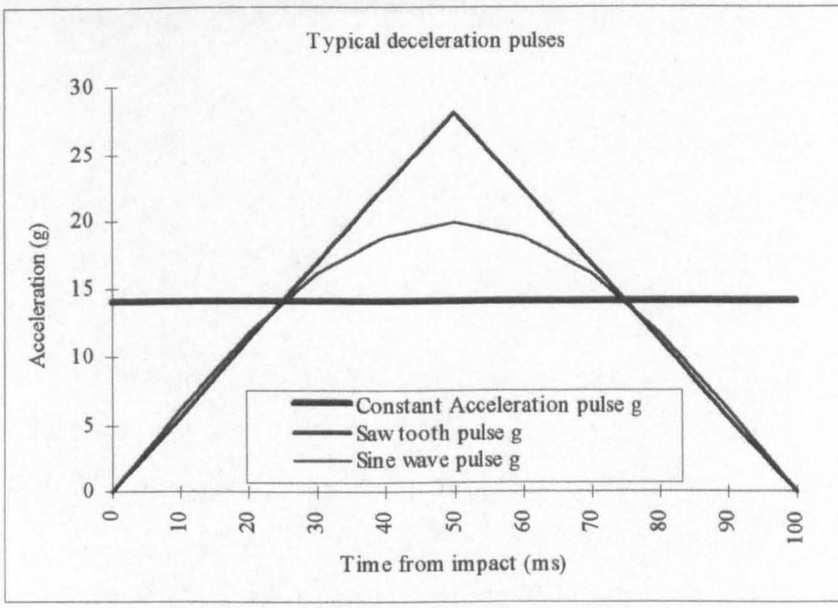


Figure 4.4 Deceleration pulses

The deceleration experienced by the occupant is dependent upon the coupling between the occupant and passenger cell, which for CRS is determined by how rigidly both the occupant and CRS are attached. If the coupling is poor through loose belts the vehicle safety cell can have almost, or completely stopped before the occupant loads the belts (i.e. makes contact with them at the pre impact velocity). This can result in the stopping distance of the occupant being small, (controlled by the distortion of the restraint system) as opposed to the longer more controlled deceleration offered by the 'crumple zone'. Neilson ID [4.5] describes calculations based on simple spring/mass systems to predict the coupling between sled and occupant, and hence a prediction of occupant response. Optimum coupling of the occupant to the vehicle has yet to be perfected.

All restraint systems should be worn tightly to secure the occupant to the passenger cell. However, in practice belts are worn slightly less than tight for comfort. This initial slackness (and its take-up) combined with the seat cushion and restraint webbing characteristics subjects the occupant to a deceleration rate that is greater than that of the vehicle. The magnitude of this amplification, defined as peak wearer deceleration/mean vehicle deceleration, depends on a number of factors such as the rebound of the safety cell, input pulse profile and the interaction between safety cell and occupant. The amplification factor (designated 'C') for belt retained child restraint systems are, typically, of the order of 2-3.

Figure 4.5 is typical for an occupant restraint system and shows a peak chest deceleration approximately twice that of the vehicle safety cell, approximately three times that of the mean safety cell pulse. In this example with limited coupling between occupant and vehicle, the occupant experiences little deceleration until a significant part of the vehicle deceleration pulse has been completed. In extreme cases of very slack belts and thick soft seat cushions, the vehicle may have almost stopped before the occupant loads the restraint system and the amplification factor will be higher, the deceleration of the occupant being controlled to a large extent by the deformation of the belt system.

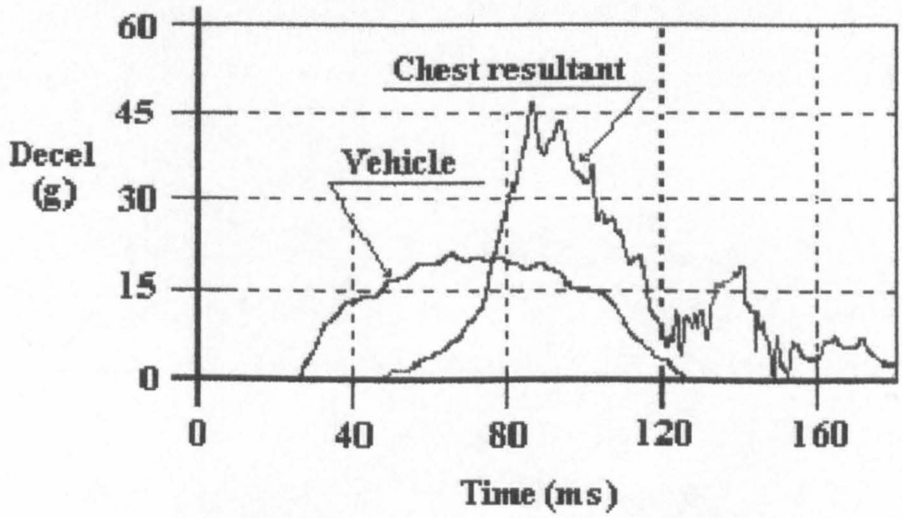


Figure 4.5 Typical deceleration profile

4.2.2. Vehicle Design Relating to Rear Impact Protection

In a rear impact, crumple zones, this time at the rear of the vehicle, progressively collapse and absorb the energy of impact and, again mitigate acceleration levels experienced by the occupants in the safety cell. In some large estate vehicles, the luggage compartment in the rear crumple zone may be fitted with additional child seating, leaving the occupant more vulnerable to injury.

The particular concern associated with rear impacts is uncontrolled motion of the unrestrained head resulting in soft tissue neck injuries, often termed as "whiplash". To minimise such injuries in adults, vehicles are now equipped with head restraints constructed of energy absorbing material. The purpose of such devices is to ensure the head and neck remain in an acceptable position with respect to the occupants torso, avoiding excessive neck extension (hyper-extension). Whilst these may be beneficial for the older child using a belt restrained booster cushion, they are of little consequence for younger children in more conventional CRS as the neck and head are within the seat shell.

4.2.3. Vehicle Design Relating to Side Impact Protection

Side impacts pose particular problems to vehicle manufacturers due mainly to the proximity of the occupant to the striking vehicle. In a frontal impact, there is a considerable distance (in relative terms) between the occupant in the safety cell and the struck object allowing the incorporation of deformable material to absorb the energy of the impact and control the acceleration levels imposed upon an occupant. In a side impact the striking vehicle is no more than the door panel thickness away from an occupant on the struck side. Intrusion is unavoidable and compounded by the limitations of restraint design. Occupant restraint systems are designed primarily for forward impacts and, consequently, are of limited efficacy when loaded from the side.

In a central 90° side impact, at 50 km/h, of a medium sized four door vehicle with a CRS, positioned on the struck side, restraining an appropriately aged child, the following typical train of events takes place:-

> The 'target' vehicle side structure (doors and 'B' pillar) deforms rapidly inwards accelerating up to almost the velocity of the impacting vehicle. During this phase, the intruding structure will impact the child/CRS. The pattern of deformation depends on the area of contact on the 'target' vehicle. Figures 4.6 and 4.7 show this from both the vehicle interior and exterior perspective. (Compact vehicles may not suffer such extensive intrusion during this initial phase as the impact load passes directly into the rigid structure of the target vehicle in the areas of both the front and rear wheels).

Figure 4.6 Intruding structure hitting struck side occupant[1]

Figure 4.7 'B' pillar folding inwards about door rebates [1]

[1] Photograph courtesy of TRL

- During the above initial phase of the event (up to approximately 20 ms from the moment of impact in a perpendicular 50 km/h event) the 'target' vehicle remains comparatively stationary relative to the ground. Subsequently, it begins to accelerate laterally until it reaches the now reduced velocity of the 'bullet' vehicle.

- As the target vehicle accelerates from under them, the occupants will strike the intruding interior side structure. Since CRS retention to the vehicle structure is primarily effected by the lap section of the adult belt, it tends to be the less well retained upper body and head of the child that make contact. Figures 4.8 and 4.9 show this, again from an interior and exterior perspective.

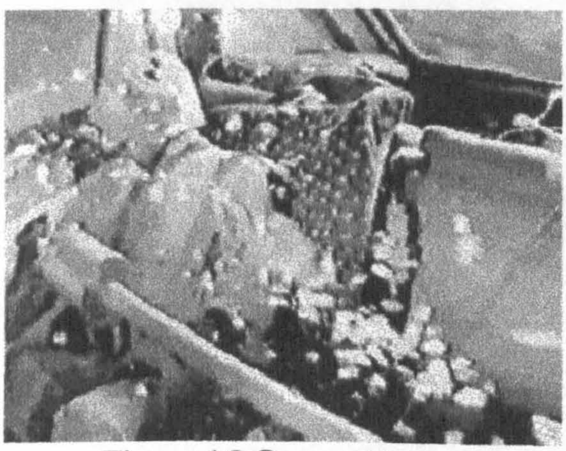


Figure 4.8 Occupant contact with intruded structure [1]

Figure 4.9 Exterior view of side impact occupant motion (adult shown) [1]

It is the case, that if insufficiently restrained the head, in the case of an adult or larger child, can not only make violent contact with the intruded door structure, but in extreme cases be projected out of the side window opening sufficiently to contact the front of the 'bullet' vehicle.

It is due to the above that side impacts pose particular concerns from the point of view of head, thoracic and pelvic injuries sustained during either the initial intrusion phase or the later direct contact phase.

[1] Photograph courtesy of TRL

To mitigate injuries resulting from side impacts, vehicle doors have rigid side impact bars to minimise intrusion and, increasingly, side impact airbags to force the occupant away from the intruding structure, header rail air bags to minimise potential head contacts and seats that move laterally, again to force the occupant to move away from the intruding structure.

From 1998 European type approval requirements for new vehicles will include side impact assessment employing a moving deformable barrier at an impact velocity of 50 km/h [4.3] and similar to that shown in figures 4.6 to 4.9 above. The acceptance criteria will be based upon the response of adult manikins to the impact but not child manikins.

The Side Swipe

A particularly dangerous type of impact with respect to rear seat child occupants is the side swipe from the front as when vehicles impact front to side at an angle of less than 90° with the 'bullet' vehicle initially impacting the forward side section of the of the target car (see figure 4.10). The initial impact forces the side and 'B' pillar towards the centre of the 'target' vehicle and this with the induced forward movement of the rear restrained occupant makes head contact with the sharp edges of the 'B' pillar etc possible.

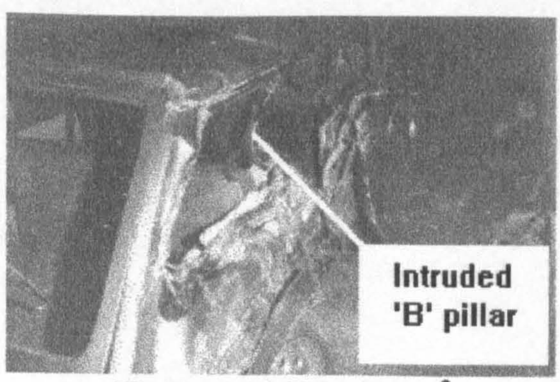


Figure 4.10 Side swipe [2]

4.3. CRS Occupant and Air Bag Interaction

There are concerns relating to the injurious effects upon out of position occupants of vehicles caused by the deployment of supplementary inflatable restraints (SIR). The primary concern has emanated from the USA where 44 infant/child fatalities were reported associated with frontal SIR to September 1997 [4.6]. (US vehicles employ larger air bags,

[2] Photograph from RSEL database

as in many cases they act as the primary restraint system due to the low usage rate of safety belts, some triggering at impact velocities as low as 10 mph).

In a frontal crash and depending upon the impact severity and vehicle construction, there is, typically, 25-30 ms between impact and the occupant commencing to move forward inside the vehicle. During this period the air bag is deployed allowing the approaching occupant to meet the inflated bag and ride down as it deflates. Due to the limited time over which accident detection and triggering occurs, air bag deployment velocities of at least 50 m/s are typical.

It should be noted at this point that any out of position occupant child or adult can be at risk of injury from deployment of a supplementary inflatable restraint (SIR). Being out of position ranges from children standing in the footwell to adults leaning or reaching forward to the glove box.

The interaction of rear facing infant carrier restraints and frontal air bags pose particular problems because the occupant's head is immediately adjacent to the instrument panel housing the air bag, which, on deployment, has resulted in reported fatalities.

The proximity of an occupants (in particular a child) head, has also been highlighted recently (since February 1999) as cause for concern with respect to side SIR. Again it is the out of position occupant who is particularly vulnerable, e.g. a child sleeping with its head resting on the door of a vehicle.

Addressing the CRS air bag interaction problem

Currently all vehicle manufacturers in Europe and North America are required to affix warning labels to vehicles equipped with front passenger seat air bag indicating there incompatibility with rear facing CRS. However, as yet there is little consistency in either the image/wording on the label or its positioning within the vehicle. This situation is/has been addressed by the ISO working group on child restraints.

One solution to the concern is to disable the air bag in question when the seating position is occupied by an appropriate rear facing CRS. This can be achieved manually by the driver

using a switch, or as various European manufacturers are developing, an intelligent system that can detect a rear facing CRS and automatically disable the SIR.
Both the above solutions have potential drawbacks. Firstly would the manually disconnected SIR be reactivated by the driver when the seat was occupied by an adult?, and can it be guaranteed that an automatic system be full proof, in either the adult occupant or infant occupant situation. Which would be the default condition?.

It is worthy of note that the Isofix CRS concept with rigid anchor points offers a considerable advantage in the area of CRS position/type detection due to the availability of positive attachments to the vehicle seat which can be employed to activate disabling devices when a rear facing Isofix CRS is in use.

4.4. Vehicle Compatibility as a Factor in Accident Severity

The compatibility between vehicles involved in accidents can be a significant factor in the outcome for the occupants. The trend towards larger, heavier, and consequently stiffer vehicles, (e.g. off-road 4x4 type utility vehicles), can have undesirable effects on the occupants of smaller, lighter passenger cars when involved in accidents with these larger vehicles.

4.4.1. Vehicle mass as a factor in accident severity

Vehicle mass plays a role in all accidents, particularly in vehicle to vehicle accidents, where one vehicle is heavier than the other. This can best be imagined if we consider the extreme case of a head on accident between a small car (mass 1000 kg) and a heavy commercial vehicle (mass 40000 kg) both travelling at 50 km/h (13.88 m/s). Assuming the vehicles to be rigid bodies the law of conservation of linear momentum dictates that the heavy commercial would only experience a velocity change of 2.5 km/h, insignificant in comparison to the velocity change experienced by the car, at 97.5 km/h. It would be reasonable to presume that the occupants of the car would be unlikely to survive even if optimally restrained, due to the high acceleration forces imposed and the inevitable considerable intrusion due to structural deformation of the car's safety cell. In contrast the occupant of the truck would be unlikely to suffer serious injury assuming no local intrusion took place.

Greater relative mass increases vehicle occupant safety. Evans. L 1996 [4.7] states that 'doubling the mass of a vehicle reduces the occupant risk by about 50%'. In addition he points out that the advantages of increased mass are not only confined to vehicle to vehicle accidents (one would expect that if all vehicles were small there would be no disadvantage).

The conclusion with regard to frontal impact safety would seem to indicate that large (high mass) vehicles with long uniformly deforming crumple zones are desirable from an occupants point of view. However the affect on other road users of lighter vehicles and pedestrians etc. may be less positive.

Two further factors effecting the compatibility between vehicles in an impact are stiffness and geometry.

4.4.2. Vehicle frontal stiffness as a factor in accident severity

The stiffness of the energy absorbing 'crumple zone' ahead of the passenger safety cell is a function of the mass of the vehicle and the available length of the deformable zone. Given that the length of deformation is controlled closely, primarily by the aesthetics of the vehicle. If the optimum constant deceleration pulse is to be retained for the occupants in a barrier type impact the stiffness of the crumple zone must in practice reflect the mass of the vehicle. When vehicles of incompatible stiffness collide (head on) it is inevitable that the crumple zone of the lower stiffness vehicle will tend to deform before the stiffer vehicle. This results in a greater probability of deformation of the passenger safety cell of the low stiffness vehicle with the potential for intrusion injuries. It would be possible to increase the stiffness of the low mass low stiffness vehicle to improve the compatibility with the high mass stiffer partner, but the occupants would be commensurably disadvantaged in an impact with a rigid barrier or small vehicle of similar mass due to loss of potential ride down distance. The alternative would be to reduce the stiffness and hence mass of the larger vehicle, or to increase the length of the crumple zone on the larger vehicle, hence enabling its stiffness to be lowered, benefiting the occupants of the smaller vehicle. Neither of these options would appear to be immediately practical.

4.4.3. Vehicle geometry as a factor in accident severity

The final factor affecting vehicle compatibility in a frontal impact (as well as other types) is geometry. Large off road (4x4) type vehicles as well as being generally heavier and stiffer than small passenger cars, are commonly much taller. This disparity in height results in the energy absorbing structures failing to contact optimally in an impact scenario. The taller vehicle structure tends to over ride the crumple zone on the small vehicle, rendering it ineffective. The outcome for the occupants of the larger vehicle is potentially much more favourable than that of the occupants of the smaller vehicle which will be liable to the possibility of serious intrusion.

The implications of vehicle incompatibility on the safety of child occupants is not inconsiderable, when one considers that children are frequently transported in the second car in a family which may be an older, smaller/lighter vehicle equipped with fewer less advanced safety features.

4.5. Impact type as a factor in accident severity

Offset frontal impact involving the loading of only one side of a vehicle (see figure 4.1) is potentially more serious than a distributed frontal impact as the impact energy is concentrated on one side of the vehicle. The crumple zone of older vehicles was designed to absorb the impact energy of a distributed impact by deformation of both chassis side frame members. In the overlap type event, only one of the energy absorbing members has to decelerate the occupant cell and this can result in greater local intrusion.

Front seat occupants may, consequently, be at a disadvantage if seated on the struck side. However due to the induced rotation of the vehicle after impact it is possible for an occupant of a rear non struck side seating position to be subjected to a lower deceleration pulse as the overall stopping distance could be greater.

4.6. Vehicle Velocity as a Factor in Accident Severity

The Kinetic energy of impact is a function of the square of the velocity which is an important consideration for occupant restraint systems. Currently certification requirements dictate that both adult and child restraint systems must provide a prescribed level of protection at up to 50 km/h in a simulated impact.

The new European Vehicle Type Approval Test for frontal offset impacts are to be conducted at 56 km/h [4.2], whereas the recent UK Euro NCAP (New Car Assessment Programme) tests that included assessment of child restraints were carried out at 64 km/h. On the struck side this would increase the kinetic energy by some 56% over the standard approval test (ECE R44 03) for child restraints. This increased energy of impact, coupled with the movement towards small cars with small rear seats raises concerns over CRS performance. Given the borderline performance of most adult belt retained CRS when tested at 50 km/h, the current generation of devices are unlikely to meet the current dynamic acceptance criteria if the test requirement velocity for CRS were to be increased.

This should accelerate the development of the Isofix attachment concept.

5. PHYSIOLOGICAL AND ANATOMICAL PROPERTIES OF THE CHILD

Children are not scaled down adults as they possess many fundamental differences when compared to a fully developed adult, some more obvious than others (Burdi et al 1969 [5.1]). This chapter outlines the important physiological and anatomical differences between children and adults and show how these influence the design of CRS and further how requirements change as the child grows.

5.1. Child Anthropometry

5.1.1. Mass

The rate of mass increase is not linear throughout childhood (see figure 5.1) with accelerated growth around 7 years and 14 years (growth spurts), although the greatest increase is during the first year of life when infant mass almost doubles. These changes fundamentally affect the design of child restraint systems.

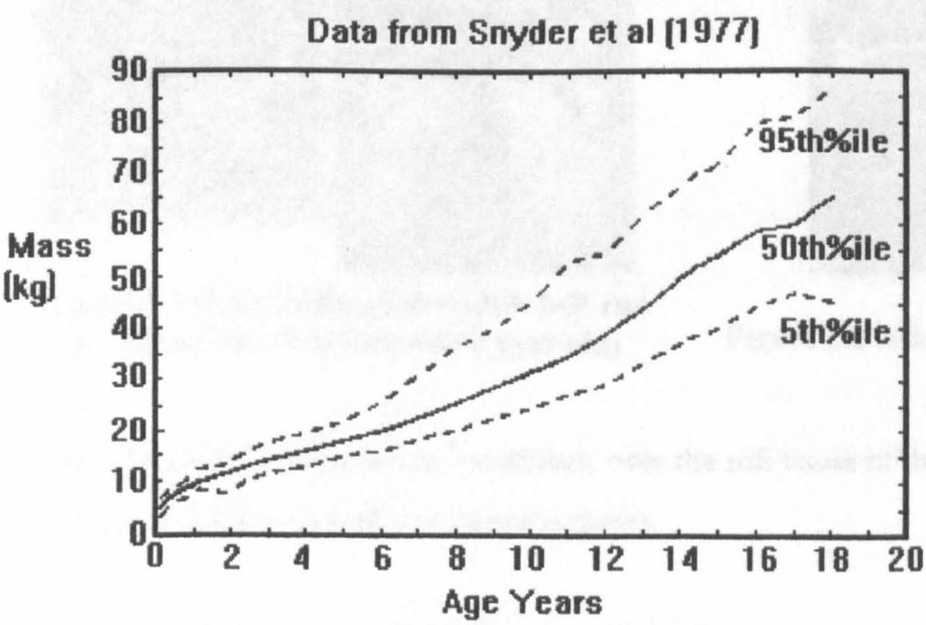


Figure 5.1 Increase in mass with age for the child/adolescent population in the 5th%ile to 95th%ile range [5.2]

Vehicle manufacturers design their product for adults in the 5th%ile adult female (50 kg) to 95th%ile male (95 kg [European] male). Since this minimum mass of 50 kg is equivalent to a 50th%ile child aged 14 years, it follows that the belts used for adult restraint systems are significantly stiffer than that needed to retain and control the deceleration of children less than 14 years of age. Figure 5.1 describes the increase in mass with age for the combined male/female child population in the 5th to 95th%ile range. Snyder et al (1977)[5.2]. It should be noted that the population for males and females differs slightly.

5.1.2. Stature

The stature of an infant or small child is much smaller than even a 5th%ile female so adult belt anchorage positions and belt runs are unsuitable for use by a small child. Figures 5.2 and 5.3 illustrate the concern about diagonal belt location and its proximity to the child's neck which may pose a potential risk of serious injury because during forward movement the belt acts as a fulcrum about which the head can pivot. The diagonal belt run for adults shows the belt running over the shoulder, well clear of the neck.

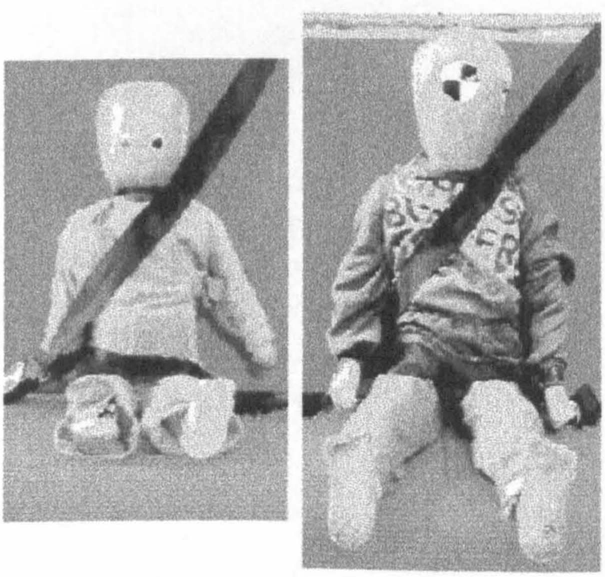


Figure 5.2 Unsuitability of the adult belt run and anchorage (9 month and 3 year old)

Figure 5.3 Adult belt run on adult

Further, the adult lap belt section lies directly over the soft tissue of the abdomen of a child and makes this area vulnerable to internal injuries.

Child height exhibits a non linear trend with age similar to child mass. Figure 5.4 again based on data from Snyder et al, showing the variation in height of children/adolescents with age for the combined male/female child population in the 5th to 95th%ile range.

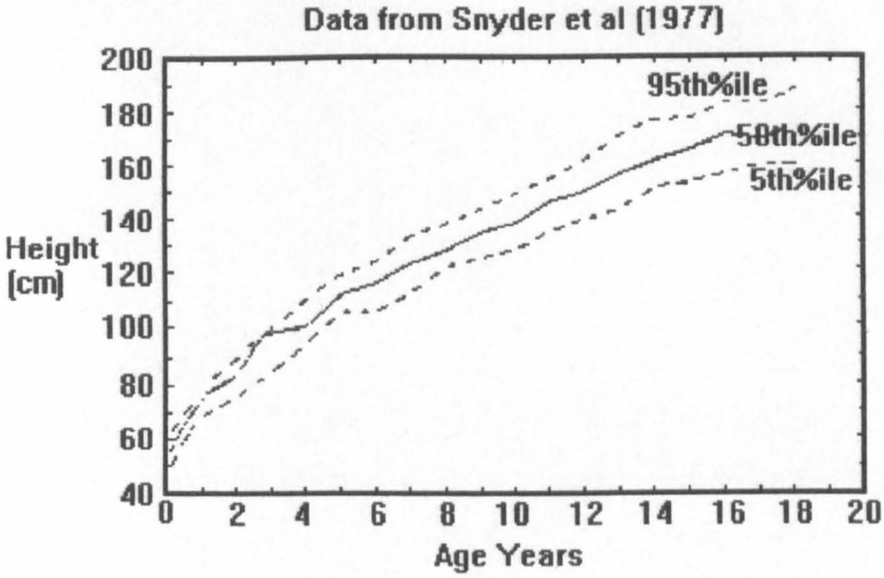


Figure 5.4 Increase in total height with age for the child/adolescent population in the 5th%ile to 95th%ile range [5.2]

Maximum height growth rate occurs in the very early years of life, particularly the first year. Thus the range of heights must be taken into account by the CRS designer. Not only must the overall dimensions encompass the proportions of the larger child in the CRS mass/age group but in addition the smaller child must not be disadvantaged. The reference Snyder et al (1977) [5.2] provides much data in this respect, e.g. seated heights, seated CG location etc.

Sitting height

The small child's body mass is concentrated in its upper section. The sitting height of an infant at birth represents approximately 70% of its total height compared with a figure of 57% at 3 years of age, and around 50% by the teenage years. In the infant and younger child the head is disproportionally large which raises the body CG (see figure 5.5) and this is a further important consideration for the CRS designer and, hence, the preference for full harness type child restraints.

Full harness type restraints are of benefit over a conventional lap and diagonal vehicle belt system with respect to this issue, as the tendency in a frontal impact for the higher C of G to propel the upper torso over the diagonal section of such an adult type belt is eliminated.

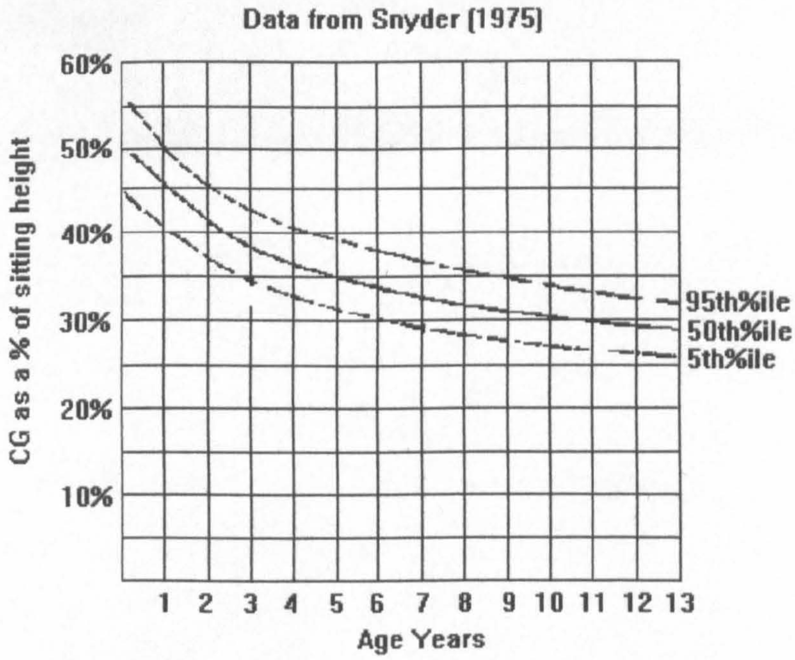


Figure 5.5 CG as a percentage of the sitting height for the child/adolescent [5.2]

The neck muscles in infants are insufficient to resist the violent head motion induced in an impact. Generally it is not until the child is at least nine months old that it can support the mass of its own head so it is sensible for this reason - and others - to transport infants in a rear facing configuration. This minimises head movement relative to the torso in a frontal impact situation.

5.2. Skeletal and Structural Characteristics

5.2.1. Tissue

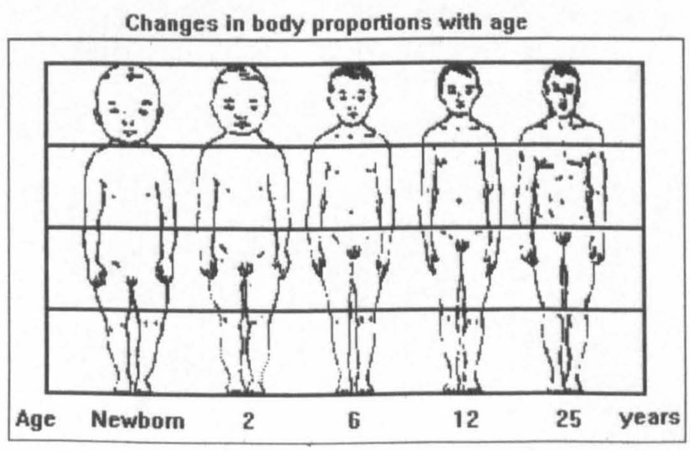
The thickness of subcutaneous tissue of the very young infant increases rapidly during its first nine months, causing problems when securing an infant in a restraint (another reason for rear facing restraints). By the age of five, tissue thickness will have reduced by about 50%, thus easing this particular problem.

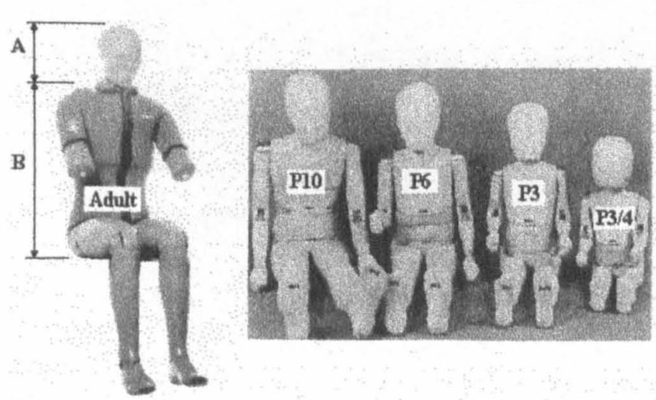
5.2.2. Head and Neck

Proportions

The head of an infant or small child is disproportionally large for its body size [5.1] (see figure 5.6). It is, in effect, a large mass supported on a weak neck structure and, therefore, CRS must offer appropriate levels of support to the head of an infant or younger child.

The size and mass of a child's head has two potentially disadvantageous effects, namely, a greater possibility of contact and injury in an impact and the potential for ejection from a restraint system due to relatively high centre of mass of the seated child.





Dimension/Mass	Manikin (P Number relates to child age)				
	Adult (75 kg)	P10 (32 kg)	P6 (22 kg)	P3 (15 kg)	P3/4 (9 kg)
Head/Neck Length (mm) **(A)**	250	230	230	185	170
Sitting shoulder Height (mm) **(B)**	530	485	405	335	280
Head/Neck Mass (kg)	4.70	3.60	3.45	2.70	2.20
Torso Mass (kg)	29.70	12.30	8.45	5.80	3.40

Figure 5.6 Indicating the relative body proportions of children in relation to adults[1].

[1] Data has been drawn from Burdi et al 1969 [5.1] and available anthropomorphic (TNO 50th%ile) manikin specifications.

Ratio of face to cranium

The ratio of the face to cranium in infants is about 1:8 at birth compared with 1:2.5 for an adult. The cranium houses the brain which is relatively large in children, attaining about 70% of its adult mass at the age of 18 months, in particular the frontal lobe (Burdi [5.1]). Any impact contact between the cranium and the vehicle structure is more likely to result in brain injury.

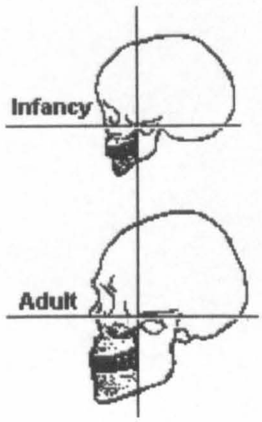


Figure 5.7 Cranium size relative to face [5.1]

Cranium strength

The cranium of the adult consists of a number of fused bones forming a rigid structure whilst that of a child is thinner and weaker and more flexible. The early pre-natal infant brain is enclosed in a cartilage and fibrous membrane and with ossification the bone gradually spreads outwards. However, at the time of birth the growth of several of these bones has not been completed and the head comprises six soft spots or fontanelles that separate the bones and where the brain is protected by skin and membranes only. Eventually the bones are fused together, to complete the cranium and enclose the brain.

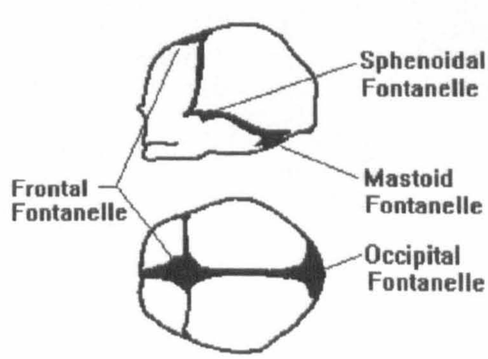


Figure 5.8 Infant fontanelles [5.1]

Neck

When compared to the adult, the child's neck is underdeveloped in comparison, this when combined with a relatively 'larger' head of the child results in the possibility of it being subject to relatively higher loads.

The neck or cervical spine (vertebrae designation C1 to C8) of a young child is commonly very mobile due to the under developed muscle and ligament structure. To compound the potential for neck injury, at birth the cervical vertebra will not have completed the ossification process to form bone. Further, the young child's vertebra possess a much greater mobility with respect to horizontal motion due to the more horizontal faces of the facets compared to the adult, increasing the potential (until about 8 years of age) for damage. Finally, the child's neck differs from the adults with respect to the effective fulcrum in bending, the child being higher at C2-C3, where as the adults is at C5-C6.

5.2.3. Torso

The torso comprises the upper and lower torso, separated by the respiratory diaphragm. The upper torso is the thorax or chest comprising of a bone/cartilaginous cage, and encloses vital pulmonary and cardiovascular organs, whilst the lower torso comprises the abdomen which has little bone to protect the digestive organs, liver, spleen and kidneys. Finally, providing a mounting structure for the lower limbs is the bony pelvis, which contains the soft tissue supporting the above vital organs retained by muscle arrangements. Keeping all these in line is the spine or vertebral column , running down the back of the torso from the base of the skull to the coccyx. The spinal column consists of a stack of ring-like bones (vertebrae designation [thorax] T1 to T12, [lumber] L1 to L5) through which runs the spinal chord which terminates at the 1st or 2nd lumber vertebra.

5.2.3.1. Thorax

After the head/brain, the organs of the chest, the lungs, heart and major blood vessels are the second most important with respect to life threatening injury in the case of restrained occupants (see section 3.6). Any serious injury sustained by these organs can be life threatening.

There are three sections within the rib cage, two pleural sections containing the lungs, and the mediastinum section containing the heart its blood vessels and other organs. Injuries to any of these major organs due to rupture or puncture is considered serious.

The protective (bony/ cartilaginous) cage constraining the organs of the thorax consists of the sternum at the front and the thoracic spine at the rear. Forming the container are the twelve pairs of ribs, connected to the thoracic spine at the rear. However, only the top seven pairs are attached to the sternum by cartilaginous members at the front. The semi flexible nature of the structure allows the chest to expand/contract to facilitate breathing.

In the child the chest wall is thin and elastic and able to deflect to a greater extent than the adult making the underlying organs more vulnerable. Harness type restraints more evenly distribute any load on the chest and, therefore, are more appropriate than the single diagonal strap of the adult belt.

5.2.3.2. Abdomen

The protection offered to vulnerable organs of the lower torso by the rib cage of the young child is comparatively less than that offered by the fully developed rib cage structure of the adult. This, combined with less well developed abdominal muscles, can leave organs of the upper abdomen comparatively more vulnerable. Abdominal injuries are often due to poorly located lap belt sections of a restraint that directly loads the abdomen often when the child slips under the lap belt (known as submarining). This is eliminated by incorporating a crotch strap into the harness type restraints.

5.2.3.3. Pelvic region

A major factor in adult belt system design is the ability of the adult lap belt to be retained in position over the hips (see figure 5.9) by the iliac crests of the pelvis under which the belt hooks during an impact, thus minimising the potential for submarining. It is not until the age of approximately 10 years that the iliac crests develop sufficiently for belt retention.

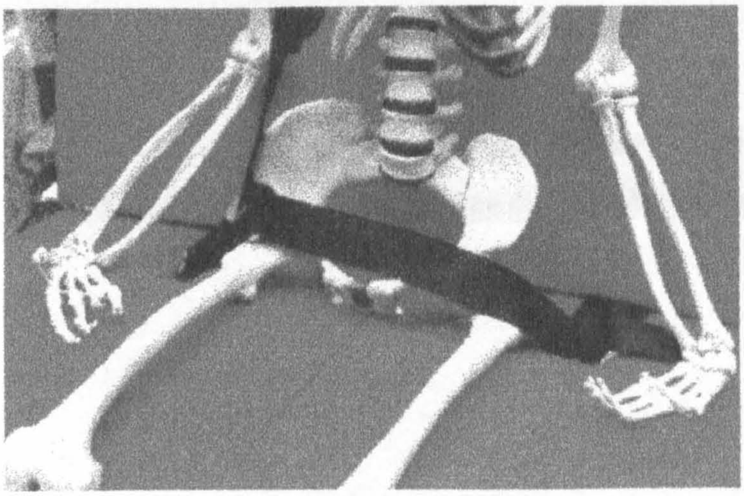


Figure 5.9 Iliac crests essential for effective location of a lap belt.

5.2.4. Extremities

Injuries to a child's arms and legs, however unpleasant, are not considered to be life threatening and do not at present feature prominently in any restraint design process.

Summary

- The child's age, size, stature and mass are fundamental factors in any restraint system.
- Contact with the interior of the vehicle must be avoided, particularly head and the chest.
- Belt/harness configuration is an important factor, and must be appropriate for the age (mass) of the child.
- For the younger child, rear facing seating configurations are beneficial, due to the minimising of load concentration points and neck deflections.
- Restraint systems must incorporate features that prevent abdominal injuries from the restraint itself (submarining).

6. OCCUPANT RESTRAINT DESIGN

The basic concept of preventing death or injury in a survivable motor vehicle accident have been described previously in chapter 4 of this document.

In this section, a résumé of adult restraint design is followed by a summary of restraint designs specifically for children.

6.1. Adult restraint systems (assuming forward facing seating)

All restraint systems attempt to achieve optimal occupant deceleration whilst avoiding contact with the vehicle interior. Such systems may comprise air bags to prevent ultimate contact with the interior (and assist in the deceleration), collapsible steering columns to mitigate driver chest injuries, and safety belts and pretensioners (combined with, in the front seats, knee bolsters) to couple the occupant as firmly as possible to the safety cell. The belt anchors may be equipped with webbing grabbers to minimise spool-out from an automatic retractor, and possibly load limiters to mitigate loading of the chest (load limiters will however increase excursion). The modern adult restraint systems is a complex compromise that can cater only for a limited range of adults (mass, size and frailties) under certain impact circumstances (impact direction and velocity) without real time adaptation for all variables. For these reasons although affording a degree of protection from ejection, adult restraints are not ideal for restraining and controlling the deceleration of young child occupants in a vehicular accident.

Adult belt run

A child is significantly smaller in stature than even the smallest adult occupant (the 5th%ile female), for whom adult belts are designed, consequently the belt anchorage positions and belt runs, even if adjustable, can be unsuitable for use by a small child. The diagonal and lap locations of the adult belt (Figure 5.2) raises concern over potential risk of injuries to the neck and abdomen.

Mass

A 50th%ile three year old child has a body mass of 15 kg compared with the 50 kg to 95 kg range specified for the 5th%ile adult female and the 95th%ile male. Adult belt systems, therefore, have webbing that is appreciably stiffer than that needed to retain and control the deceleration of a small child. For these reasons, dedicated child restraint systems became desirable.

Dedicated child restraint systems have been available since the early 1970's[1]. The following section summarises the development of these devices for the different age groups.

Child restraint systems are defined in five groups. The European acceptance standard ECE R44 defines these as Groups '0', '0+', '1', '2' and '3'. These definitions superseded previous definitions which categorised the devices into stages.

Figure 6.1 describes the current definitions with respect to mass and shows an approximate relationship to age, although age is not defined in the standard. It also shows the approximate correlation with the older definition of restraint stages.

ECE R44 Group	0	0+	1	2	3
ECE R44 Mass of child (aprox ages)	<10 kg (0-9 months)	<13 kg (0-15 months)	9-18 kg (9 months-4 years)	15-25 kg (4-6 years)	22-36 kg (6-11 years)
Stage of restraint (old definition)	1	N/A	2	3	4
Description	Rear facing infant carrier with integral harness. The CRS is retained by the vehicle lap and diagonal belt.	Large rear facing infant carrier with integral harness. The CRS is retained by the vehicle lap and diagonal belt.	Forward facing CRS typically with integral harness. The CRS is retained by the vehicle lap and diagonal belt	Forward facing booster seat. The occupant employing the vehicle lap and diagonal belt.	Forward facing booster cushion. The occupant employing the vehicle lap and diagonal belt.
Illustration					

Figure 6.1 Restraint group definition

[1] Previously child chairs had been available, which hooked over a vehicle seat back, these however were not intended to enhance occupant safety in an impact, simply to alter the position of a child

It should be noted that some 'convertible' CRS are designed for more than one group and that some framed CRS may convert from rear facing Group 0 to forward facing Group 1 configuration. It has also been common for Group 2 booster seat backs to be detached to form a Group 3 booster cushion. More recent devices have been designed to meet the needs of Groups 1 (with integral harness), 2 and 3. ECE R44 also permits use of a booster seat with adult belt for children as young as 9 months. Although arguments can be made that this is undesirable (possible neck load concerns etc.), the somewhat crude manikins used for current certification purposes will allow such devices to pass the current limited test requirements (no neck loads being measured).

6.2 Development of Supplementary Child Restraint Systems in the UK

Group 1 CRS

The development of protective restraint systems for Group 1 children started with what were essentially child sized seat shells incorporating their own child harnesses (originally 4 point), comprising typically of 25 mm width webbing. These shells were placed in a vehicle seating location (rear), and retained permanently in position by four dedicated straps anchored to the vehicle structure, (i.e., to the parcel shelf/floor). This system worked well dynamically, although the attachment method caused difficulties as it entailed the permanent[2] loss of an adult seating position whilst the child restraint was installed even if not occupied. Furthermore when changing vehicles, the owner had the inconvenience of making new attachment points in the new vehicle structure. This process itself was prone to difficulty as the potential existed for seats to be attached to trim components instead of the vehicle structure by inexperienced persons. Figure 6.2 depicts a restraint of this type.

[2] Systems were subsequently developed to overcome this problem by the use of quickly detachable shells

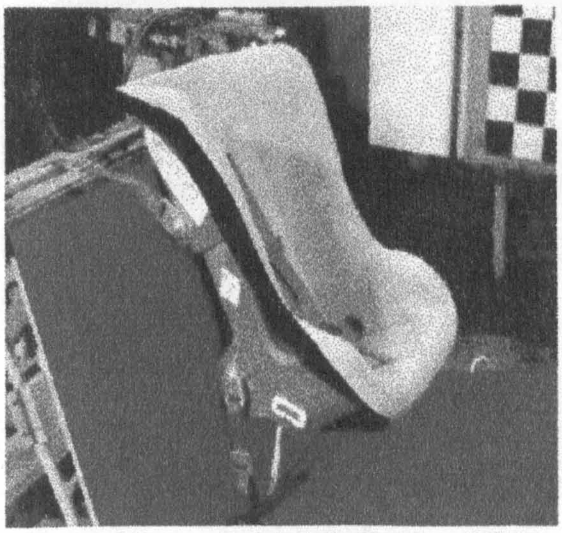


Figure 6.2 Initial shell type child restraint, incorporating dedicated attachment straps

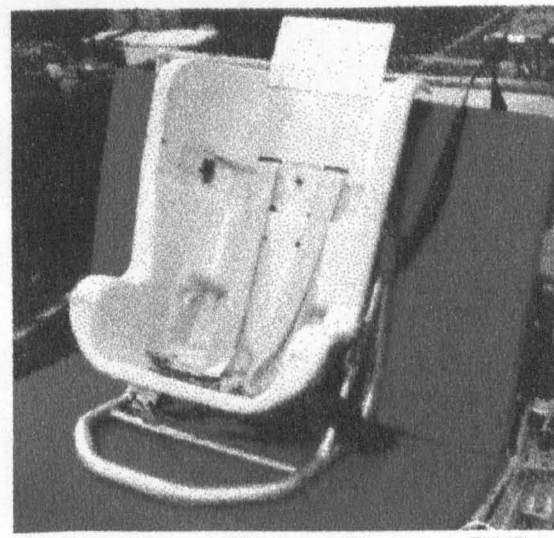


Figure 6.3 Current framed CRS, attached by vehicle belt system

A development of this system (figure 6.3), incorporated a frame resting on the seat cushion retained by the vehicle lap or lap and diagonal belt to support the seat shell with the child again restrained by a dedicated secondary harness with webbing of lower stiffness.

This type of CRS, suitable for children in the 9-15/18 kg mass range (9 months to 3-4 years of age), has dominated the market in recent years but would now appear to be declining in popularity.

Group 0 CRS

Until the late 1980's, CRS for infants up to 9 kg (0 to 9 months) comprised carry cots affixed laterally across the rear seat. A strap system similar in principal to that previously described was employed to attach the carry cot to the vehicle structure, whilst the infant was retained in position with a cover affixed over the open top. The figure below (6.4) details a typical system of this type. In approximately 1985 these carry cot restraints began to be superseded by specific infant carriers that support the child rear facing in a supine position and comprise a moulded shell with an integral light weight harness. CRS of this type are designed to be used rear facing - relative to the direction of travel - on either a vehicle front or rear seat that is equipped with a suitable adult lap and diagonal belt to secure the CRS in the vehicle (Figure 6.5 shows one such typical infant carrier).

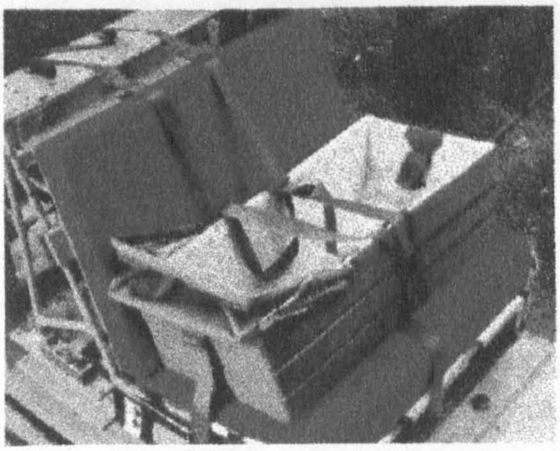


Figure 6.4 Older carry cot type restraint

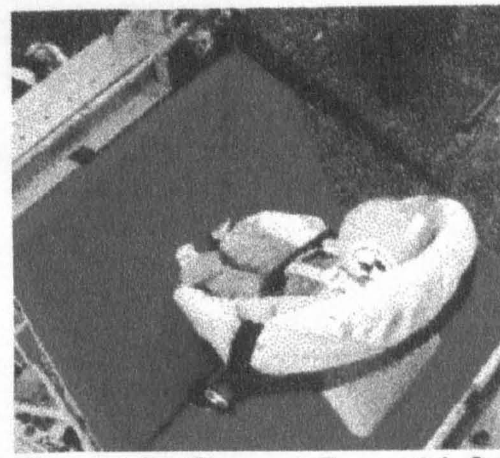


Figure 6.5 Current Group 0 infant carrier

Devices designated Group 0+ are also available. These devices are essentially larger Group 0 infant carriers designed to keep infants up to approximately 15-18 months of age in the more beneficial rear facing configuration. Such devices may be difficult to fit in small cars.

Group 2 and 3 CRS

Before the universal availability of adult lap/diagonal rear seat belts, older children of 15/18-36 kg (4 to 10 years) could be restrained by child harnesses. These were essentially a 4 point harness system (lap belt and two shoulder straps) bolted into the rear of any vehicle and are now obsolete. But again, as with early child seats and carry cot restraints, they required attachment to suitable structure giving acceptable restraint geometry. Such devices can present concerns with respect to submarining of the occupant due to the lap belt being pulled upwards by the chest section.

Nowadays, children in this age group are restrained by conventional lap and diagonal adult belt complemented by belt positioning booster seats (booster cushion with integral back) and booster cushions. These devices are designed to present the child to an adult belt system in a way that the detrimental consequences of the adult belt run are minimised. The booster seat, for the younger end of this age range (Group 2), offers some side and rear head protection and some head side support if the child falls asleep. Figures 6.6 and 6.7 detail a typical booster cushion and booster seat.

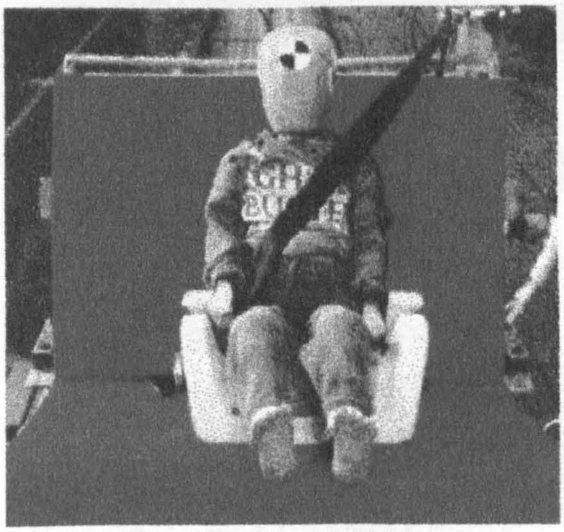


Figure 6.6 Booster cushion

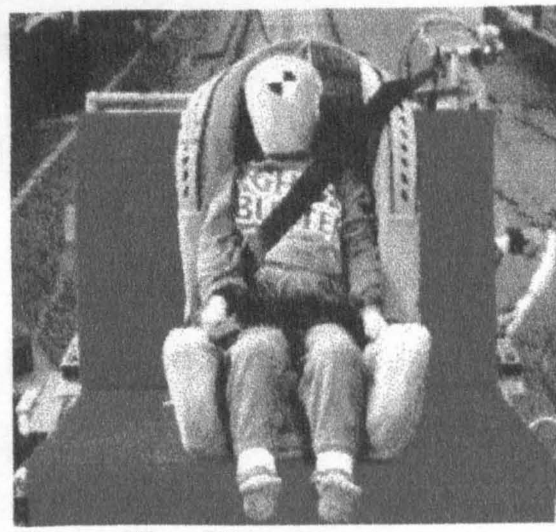


Figure 6.7 Booster seat

There are other major CRS types used elsewhere in the world, although rarely seen in the UK such as the shield type widely used in North America and some European countries, a typical North American example is shown in figure 6.8.

Figure 6.8 Shield type restraint

This type of CRS essentially consists of a booster cushion secured by a vehicle lap belt. The occupant is restrained in position by a shield forming an integral part of the booster to control movement of the upper torso. The shield may be supplemented by an integral lap strap. Designs of this type spread the upper torso loads over the thorax and abdomen which may not be considered desirable by some.

Another type of CRS, used widely in Scandinavia, is the larger rear facing child seat used for children up to four years of age. These seats are rear facing versions of the conventional Group 1 type devices seen in the UK.

There is evidence that an impact with a major frontal component these rear acing devices do offer benefits. However, larger rear facing CRS present installation problems due to the lack of space available in modern smaller vehicles, the centre rear being the only practical position in some cases. Whilst the front seating position offers space advantages, there remains concern about potential intrusion. Front passenger air bags preclude front seat installation of any rear facing devices.

Summary

The main advantage of current generation of 'universal' CRS is convenience. The majority of European systems are highly effective when installed properly adjusted and used correctly. The concern is that the vehicle-CRS interface is not always satisfactory due to the variations in seat cushion size, compliance and geometry. More significantly, installation errors on the part of the parents is the major failing.

The use of the adult belt system, whether lap or lap/diagonal to fix the CRS to the vehicle offers convenience and does encourage the use of child restraints. However this method does have disadvantages.

Adult belt geometry is primarily aimed at restraining the adult torso to minimise injuries during a dynamic event. In recent years, adult belt geometry has been improved by optimising the anchorage locations, particularly the two lower fixings that are now located further forward to reduce the possibility of submarining and associated abdominal injuries. The consequence of these revised lower anchorage positions has been a deterioration in the retention of framed CRS by adult belts both in the fore/aft direction and laterally. Furthermore, it is a long-standing concern that those adult belt systems with long buckle stalks can cause 'buckle crunching'-when the adult belt buckle lays directly on the frame of a CRS-that may cause buckle failure during a dynamic event due to undesirable/excessive loading in bending.

A major advantages of current CRS retained by the vehicle belt system is the perceived 'universal' nature of the fixing but this universality also presents significant opportunities for miss installation (see chapter 3). There is no single correct installation procedure for all commercial CRS; each is designed to work optimally only if the adult belt is routed and tensioned correctly in line with the manufacturers instructions.

The concerns about conventional belt retained CRS can be summarised thus :-

- Unsatisfactory retention of the CRS by modern adult belt systems due to geometry constraints, inertia reel spool out, resulting in greater occupant excursion and potentially increased amplification factor giving higher occupant deceleration levels and hence loading.

- Potential for incorrect fitting of the CRS to the vehicle due to the complications of both adult belt routing through the restraint and operation of belt lock off devices.

- Unpredictable effects of different seat cushion properties on installation and dynamic response.

Dedicated CRS attachments within the vehicle has long been recognised as a means of eliminating or minimising these concerns. Some vehicle manufacturers already offer built-in child restraints.

6.3. Integrated restraint systems

Integral fold away child seating systems are being incorporated into the rear seats of some 'family sector' vehicles. These Group 1 CRS (figure 6.9) typically consist of a fold away section of the rear seat back in the position normally occupied by a central arm rest and usually comprise a five point harness anchored directly to the vehicle structure. The device may double as a booster cushion for older occupants employing a centrally positioned vehicle lap and diagonal belt system. The benefits offered by integral CRS are manifest, ranging from simple uncomplicated deployment and fitting to improved dynamic performance. Both head excursion and occupant peak deceleration will be reduced through the direct anchorage of the occupant harness to the vehicle structure.

This type of CRS may not offer a comprehensive level of protection to the occupant's head in the event of a side impact. More recent after market CRS provide protective wings to the side of the head improving the potential for survival should the CRS/occupant contact objects within the interior of the vehicle in a side impact.

There is no record of integral rear facing infant carriers presently available in the UK, although Electrolux Klippan published in 1989 a proposal for an integral booster/rear facing CRS incorporated in the front seat of a car [6.1].

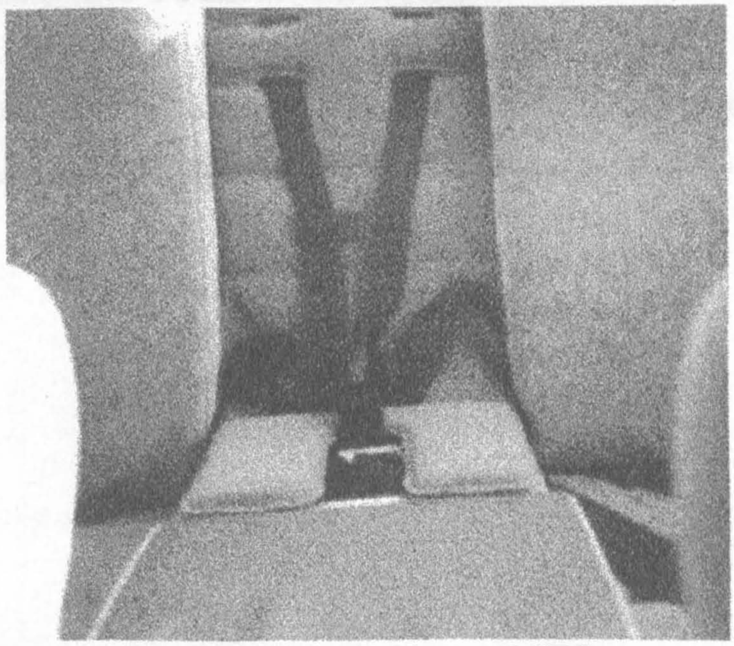


Figure 6.9 Typical integral CRS

6.4. The future of CRS in Europe and elsewhere

The concerns about conventional adult belt retained CRS have led to proposals for improved CRS to vehicle interface. This work began in the early 1990's and is co-ordinated by the International Standards Organisation (ISO) with the aim of producing an international standard system for fixing CRS to vehicles (Isofix). The aim is to specify a general attachment concept about which both CRS and vehicle manufacturers can design their products. The intended result was the provision of fixings in all new vehicles which will accommodate any suitably equipped CRS. The Isofix concept of latched-in removable CRS is intended to offer all the benefits with none of the disadvantages of integral devices (see chapter 11 for details and performance advantages).

7. INJURIES AND TOLERANCE LIMITS

This section summarises the vulnerability of the body to injuries associated with road vehicle accidents and describes injury criteria, and tolerance limits.

7.1. Injuries

The body can be divided into areas liable to risk as follows:

7.1.1. Face, Head and Neck

For restrained children the most common fatal injuries are those to the head (Rattenbury and Gloyns 1993[3.6] and Lowne, Gloyns and Roy P 1987 [3.17]) and these are most commonly associated with head contact within the vehicle interior/intruded structure.

The head consists of the face and the cranium. Facial injury may cause disfigurement, but depending upon severity, is generally not life threatening unless damage resulting in blockage of the airway is caused, impeding breathing.

Potentially more serious is damage to the cranium, and in particular to its contents the brain. Not all skull fractures constitute a serious injury. Those without an open wound, and without significant displacement of the bone may be considered a relatively minor injury. An open fracture leaves the possibility of brain infection, whilst a depressed fracture may damage the underlying organs such of the brain or its surrounding membranes. The brain is a complex structure and is liable to damage from haematoma, congealed blood as a result of bleeding within the skull, the consequence of which is pressure on the brain which can either damage brain cells directly, or restrict blood flow to sections of the brain mass due to the excess pressure created. Further, brain material comprising approximately 90% water, can be liable to serious cavitation (contra coup) injuries at the opposite side of the skull from the impact (coup) site.

Direct impacts are not the only mechanism of injury to the brain. It is possible, although rare in children, to produce inertial/shear type injuries due to excessive linear or particularly angular acceleration without head contact. An example of such an injury was described by

Lowne et al (1987) [3.17]. No head acceleration measurements are called for in the ECE R44 certification procedure.

Fatal neck injuries to restrained children, described more accurately as injuries to the upper or cervical spine (C1-C7) were less common in [3.17], although in the later data [3.6] CRS in frontal impact recorded a similar incidence of neck injuries as head injuries.

Neck injuries to belt restrained forward facing occupants in a frontal impact are often the result of submarining - effectively downward ejection through the lap section of a restraint. Submarining can result in abdominal injuries, or in the most severe cases, neck injures. Examples are described in [3.6].

The later fatality study [3.6] of children using adult belts, stated that 'there is little evidence of a major risk of life threatening neck injury being caused by the diagonal section of the adult belt, except perhaps for very young children'. This would indicate that in practice the diagonal section of the adult belt may not pose the level of risk some people prescribe to it.

Generally side impacts did not appear to pose as great a risk of neck injury as frontal impacts. The Primary concern in side impact being direct head and chest contacts as a result of severe intrusion.

The neck is a complex structure, providing support and location for the head, facilitating head movement and acts as a connecting conduit for nerves, veins/arteries, spinal chord, air-passage, trachea and larynx, and contains the muscles that enable head motion.

The bony components of the neck, or upper section of the spine is comprised of 7 cervical vertebra (C1-C7), the upper two vertebra (C1 and C2) have a specialist function and are constructed differently to the others. C1 (the Atlas) supports the base of the skull, providing the fulcrum about which the head 'nods'. C2 (the Axis) is again a specialist vertebra, having a peg like protrusion on which the C1 vertebra fits, this protrusion (which passes up into the front of the Atlas) called the 'Odontoid process or Dens' controls the rotation of the head. The remaining 5 lower vertebra of the neck are similar in structure to the other vertebra of the spine, although smaller and contribute to more exaggerated neck motions as described below.

The neck is designed to permit motion of the head relative to the torso as described in figure 7.1.

Flexion	Forward 'nodding' motion, chest towards chin.
Extension	Backwards motion, rear of head towards back.
Lateral bending	Sideways motion, side of head towards shoulder.
Rotation	Rotation of head about axis of spine.

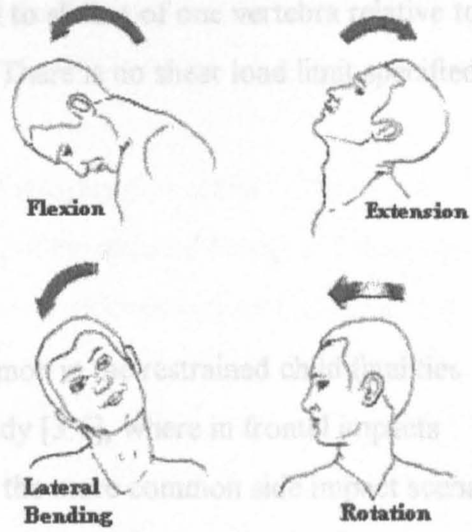


Figure 7.1 Head motion [7.12]

Any motion other than these are unnatural, and potentially damaging, as could the motions described above if taken beyond normal limits. Unnatural neck motions may be caused by compressive or tensile loading (along the axis), or shear loading by translation of the head relative to the torso. Injury can result from hyperflexion, excessive forward bending, and/or hyperextension (excessive rearward bending), sometimes referred to as 'whiplash'. Both these mechanisms can cause straining or tearing of muscles and/or damage to ligaments, nerves and blood vessels or in extreme cases damage to the vertebra and possibly the spinal cord. No neck load measurements are required in the current European CRS acceptance standard ECE R44.

Compression of the spinal column due to rapid acceleration of the torso relative to the head such as might be seen due to an impact on the top of the head, or acceleration of the torso upwards (as in the case of an aircraft ejector seat) may cause vertebra compression fractures. The ECE R44 CRS acceptance standard incorporates a 30 g limit on chest/abdomen acceleration towards the head. Similarly tensile spine loading can also result in injury. Huelke et al (1992)[7.1] quoted a source stating "In autopsy specimens the elastic infantile vertebral bodies and ligaments allow for column elongation of up to 2.0 inches, but the spinal chord ruptures if stretched more than 0.25 of an inch". No tensile load or acceleration limit is specified in ECE R44.

Further excessive shear loading of the neck can lead to sliding of one vertebra relative to the next, that may cause damage to the spinal column. There is no shear load limit specified in the acceptance standard.

7.1.2. Upper and Lower Torso

Injuries to the chest and or abdomen were less common in the restrained child fatalities study [3.17], and this is also the case in the later study [3.6], where in frontal impacts injuries were associated with submarining, whilst in the more common side impact scenario excessive intrusion was generally the cause of chest/abdominal injury due to direct contact.

Injuries to the chest can be either penetrating or blunt, and may be as a result of direct contact with the vehicle structure, or as a result of the load imparted by a restraint system. The bony chest structure of the child is thinner and more flexible than that of an adult, hence for a given load the child's chest will deflect further resulting in the potential for internal blunt injury without evidence on the surface. Conversely older adults can be at risk due to the brittleness of the ribs etc. when subjected to loading by the diagonal belt section, which can cause rib fracture and result in puncturing injuries.

The use of harness type restraints can have the benefit of distributing more desirably the load input to the chest, when compared with the single diagonal strap of the adult belt (depends upon strap width), and this is one reason for their use in CRS applications. Further some vehicle manufactures have developed 'load limiters' which are incorporated in the adult belt system to attenuate the peak levels of load seen by an adult occupants chest, potentially reducing the levels of injury.

The lower section of the torso, the abdomen, has a completely different structure to the upper section. The protection offered to vulnerable organs of the lower torso by the rib cage of the young child is comparatively less than that offered by the fully developed rib cage structure of the adult. This, combined with less well developed abdominal muscles, can leave organs of the upper abdomen comparatively more vulnerable. Injuries to the abdomen are often the result of poorly located lap belt sections of a restraint, resulting in direct loading of the abdomen. This concern, as already indicated earlier in this document is particularly evident in children due to the underdeveloped nature of the iliac crest of the pelvis, which help to locate the lap portion of a restraint. This is a situation mitigated by the use of harness type restraints including a crotch strap (to prevent submarining).

ECE R44 employs resultant chest deceleration as an acceptance criteria (< 55 g). In addition, the potential for abdominal lap belt injury can be assessed by either deformation of plasticine or damage to bubble pack type material in the abdominal cavity, alternatively close examination of video footage is used.

7.1.3. Upper and Lower Limbs

Although not as serious as injuries to the head or chest (i.e. life threatening), injuries to the extremities, e.g. arms and legs have the potential to be disabling, injuries to the joints particularly so. However, since they are unlikely to be life threatening, slightly less weight is placed upon such injuries with respect to CRS design. No measure of extremity injury is addressed by the ECE R44 standard.

7.2. Injury tolerance levels

Injury tolerance levels of vehicle occupants will to an extent depend upon age, mass, development and health. Because of these factors restraint system design is tailored to the particular age group at which the CRS is aimed. However different countries respond to tolerance limits differently. For example, Scandinavian countries commonly continue to restrain children up to at least 4 years in a rear facing configuration, where as in the UK such a CRS configuration is rarely taken beyond 9 or more recently 15 months.

Load levels (which for test purposes are measured in manikins) are described in terms of acceleration (or a time function thereof) or a measure of load imposed. The levels will vary with the body part affected and the directions of application.

Traditionally tolerance levels for occupants have been established by laboratory testing and from field data. Tests employing human volunteers are used for assessments producing low levels of reversible injury. Tests employing human surrogates, cadavers, animals or mechanical dummies permit more severe assessment and injury levels are formulated from observed results.

The suitability of the various human surrogates will be addressed later (Chapter 9).

7.2.1. Head tolerance limits

As the head is the most common area of fatal injury suffered by vehicle occupants in an impact, tolerance limits and injury criteria first focused on the head. The original work was by Lissner et al (1960), who produced a tolerance curve relating to levels of deceleration with respect to human injury/survivability. Lissner's work was then amended to be known as the Wayne State tolerance curve (Patrick et al, Wayne State, University in Michigan, USA).

The Wayne State curve of deceleration v. exposure time was developed from test data gathered using live volunteers (low level impacts), animal surrogates (medium level impacts) and cadavers (high level impacts), striking the head against flat plates and measuring the resultant injury. Figure 7.2 was constructed based on this data, showing levels of deceleration vs. exposure time.

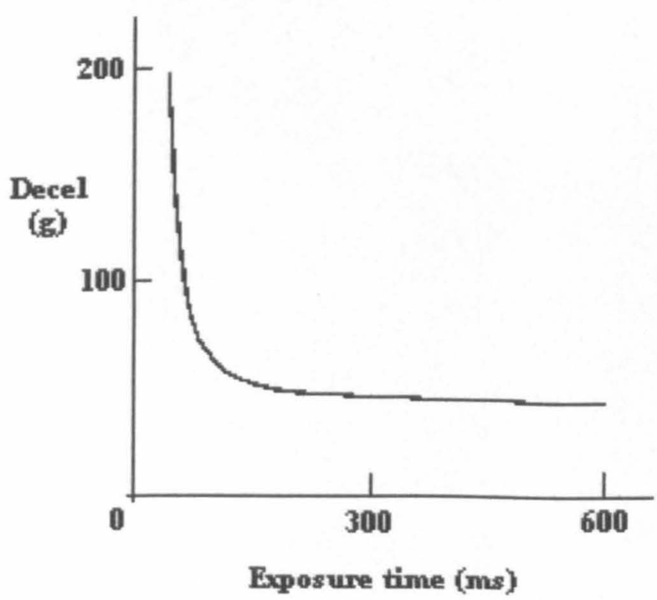


Figure 7.2 Wayne State curve

The area below the curve is considered to be generally survivable, whilst the area above is considered generally non-survivable.
The term 'generally' is used as the graph can't be considered an absolute indication of survivability.

It indicates that very high levels of acceleration can be tolerated over very short periods of time, or that constant low acceleration levels are survivable over a relatively long time scale.

To quantify the Wayne State tolerance curve in terms of an equation, a severity index called the Gadd severity index (GSI) was subsequently formulated for accelerations of 0.25-50 ms duration but outside this time window the GSI equation diverges significantly from the Wayne State curve. The limit for injury is 1000, indicating that above this value injury was probable.

$$\int_{0}^{T} a^{2.5} dt < 1000$$

Figure 7.3 Gadd severity index

The Gadd index has now been superseded by the 'Head injury criteria', or HIC.

$$HIC = max\ (t_2 - t_1)\left(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\,dt\right)^{2.5} < 1000$$

Figure 7.4 HIC severity index

Again the tolerance limit for HIC is 1000.

Both the Gadd and HIC injury criteria are related to direct contacts as a result of impact. They can be misused if applied to inertial loading of the head as they do not account for direction of loading. As described previously, for children head injury is primarily a result of contact between the head and the interior of the vehicle.

The current European CRS acceptance standard does not call for the measurement of head acceleration, however where appropriate head accelerations have been recorded in the following chapters relating to CRS testing for comparative purposes.

7.2.2. Neck tolerance limits

Neck loading limits will, to an extent probably greater than the preceding acceleration limits, depend upon the construction of the body in which they are being measured. Manikins, however complex, can only be an approximation of an actual live human.

Neck construction of manikins varies with manikin type. Many posses a rigid rubber neck affixed at the lower end to the upper torso, and at the top directly to the head (the rubber neck may be slotted at the rear to facilitate greater ease of bending in flexion than extension).

Other manikins, such as those of the TNO 'P' range, as used in the CRS evaluations reported in this document, employ an alternative neck construction. The 'P' range of child manikins use a tensioned cable spine combined with rubber neck rings. However, the main difference is found at the upper neck atlas joint which includes a 1 g pivot for the entire head.

The result of these differences in manikin construction is that neck loadings recorded in similar events may differ, particularly with respect to for/aft bending moment. Hence any tolerance limit can be seen to be particularly germane to the body or manikin in which it is being assessed.

At present there is no universal acceptance limit for neck loading with respect to child occupants which can be universally applied to data from simulations using anthropomorphic devices. However several sources of data are available relating to work carried out in the area [7.1] [7.2] [7.3] [7.4] [7.5], many of which have analysed and/or reconstructed accidents involving children in which serious neck injuries occurred. In addition some of the references attempt to suggest loading limits for children, either directly or as scaled values based upon adult limits.

The type of loading is another important factor with respect to neck loading. Since the wide spread introduction of SIR, investigations have been conducted into the potential effects upon occupants, both adults and children. However, these are primarily contact loads. The type of loading seen in the tests referred to in this document are non contact inertial loads, so it is data of this type which is of particular interest.

Loading of the neck can be measured as either axial (tension or compression), shear, bending moment, or in reality a combination of all these.

Neck loading limits have been defined in both US (FMVSS 208) and European Frontal impact standards for <u>adult</u> (Hybrid III) manikins, measured at either the upper and/or lower connections of the neck. These limits can be defined as either peak values or by time dependent corridors.

Figure 7.5 shows the peak values proposed in current changes to FMVSS 208 for a 50%ile adult manikin.

Neck tension	3.3 kN	Neck extension moment	57 N m
Neck compression	4.0 kN	Neck flexion moment	190 N m
Neck shear (fore/aft)	3.1 kN		

The above values reflect the proposed force-time limits for adult injury assessment, Melvin [7.6] shown below.

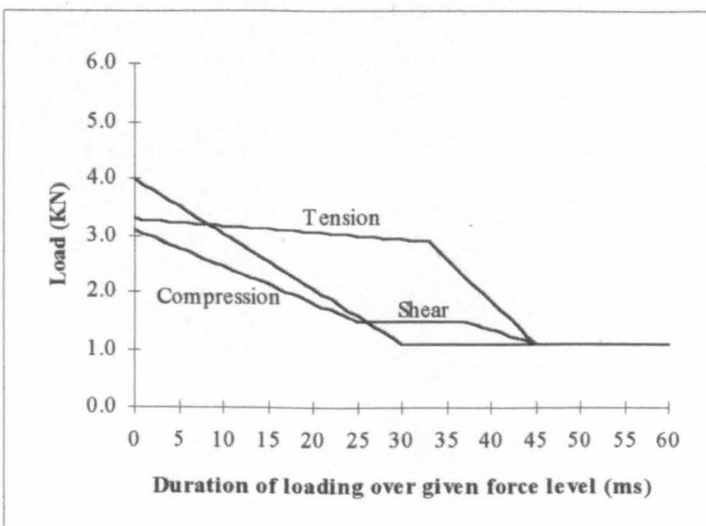


Figure 7.5 Proposed adult neck load-time limits [7.6]

For reasons mentioned previously in this document child neck injury tolerance levels in frontal impacts are lower than those for a fully developed adult, particularly so in the case of very young infants (hence the suitability of rear facing CRS). Planeth et al [7.4] suggested guidelines for a child neck protection criteria based upon accident reconstruction using a modified US P572 (solid rubber neck) manikin representing a 3 year old child. The maximum levels suggested being: axial (tensile) force 1 kN, shear force 0.3 kN and flexion bending moment 30 N m. It can be seen that these values are significantly lower than the adult values with the Hybrid III manikin. Other authors [7.7][7.8] have suggested scaling factors for adult manikins. Janssen et al [7.3] reported scaling methods conducted by Irwin A L, used to scale the design and performance of child manikins. Janssen et al [7.3] suggested the scaled 50%ile Hybrid III to be in good agreement with the values suggested by Planeth et al [7.4], with the exception of shear force which was higher at 0.95 kN.

Other references exist; Trosseille and Tarriere [7.9] reports on values obtained from accident reconstructions employing CRABI and P572C manikins representing children aged 6 months to 6 years, however few references relate to the TNO 'P' type manikin, with neck construction employing a 1 g atlas joint. Janssen et al [7.2] [7.3] conducted both sled tests including accident reconstruction and mathematical modelling, to determine the loads induced in the neck of a TNO P3/4 manikin, forward facing in frontal impacts (conventional lap belt retained four point CRS). The results with the 1 g atlas joint proved significantly lower in terms of flexion and extension bending moments, but greater in terms of both shear and tensile forces, when compared with the same manikin with a locked atlas joint. A recalculation factor was suggested for comparing locked and free neck values for this manikin.

Janssen also reviewed:- The effect of seat orientation (upright or reclined into the sleeping position) was addressed, and it was shown that neck loading was affected detrimentally in the supine position (seat back inclined from 28°-47° to vertical).

The effect of a top tether.

Finally in recognising the time dependent character of neck shear and tensile loading, a 30 ms attenuated value was introduced.

Values of neck loading presented by Janssen et al on the ECE R44 01 test bench and anchor positions, at a ΔV of 49-50 km/h for the P 3/4 manikin (forward facing, lap belt retained four point CRS) were :-

• Fx (peak)	0.81-0.85 kN	Fx (30 ms)	0.60-0.64 kN
• Fz (peak)	1.49-1.60 kN	Fz (30 ms)	1.11-1.16 kN
• Fresl't	1.66-1.81 kN		

- Mb (flexion) 2.3-2.7 N m Mb (extension) 2.5-4.3 N m
- Chest resultant (3 ms) 29-35 g
- Head resultant (3 ms) 53-58 g
- Head excursion 409-423 mm

These values were found to be slightly superior to similar tests conducted upon a small vehicle rear seat with the vehicle seat belt anchor positions (2 point belt), which reconstructed an accident resulting in neck injury (with the exception of head excursion) :-

- Fx (peak) 0.91-1.07 kN Fx (30 ms) 0.60-0.64 kN
- Fz (peak) 1.70-1.83 kN Fz (30 ms) 1.16-1.33 kN
- Fresl't 1.89-2.08 kN
- Mb (flexion) 2.1-2.3 N m Mb (extension) 3.7-4.4 N m
- Chest resultant (3 ms) 56-57 g
- Head resultant (3 ms) 76-81 g
- Head excursion 409-426 mm

The low values of flexion and extension bending moment in these tests were as a result of the 1 g atlas joint at the manikins upper neck. It should be noted that between bending in flexion on initial deceleration, and extension on rebound, the manikin chin will contact the chest, producing a bending moment on the neck considerably greater than that seen in 'free flight'.

Figure 7.6 details the neck loading observed in a TNO P3/4 manikin restrained in a five point forward facing CRS, retained by a 2 point belt, carried out by the writer during the course of the work contained in this document. The CRS was evaluated in line with the ECE R44 03 frontal impact procedure (with the R44 03 anchor positions and set up procedures) at an impact velocity of 49 km/h (test No 3634) on the test sled described in Appendix 7. It should be noted that this test was conducted without the retained shoulder grabber pads (items which are specified for this seat as standard, the advantages of which are detailed elsewhere in this document).

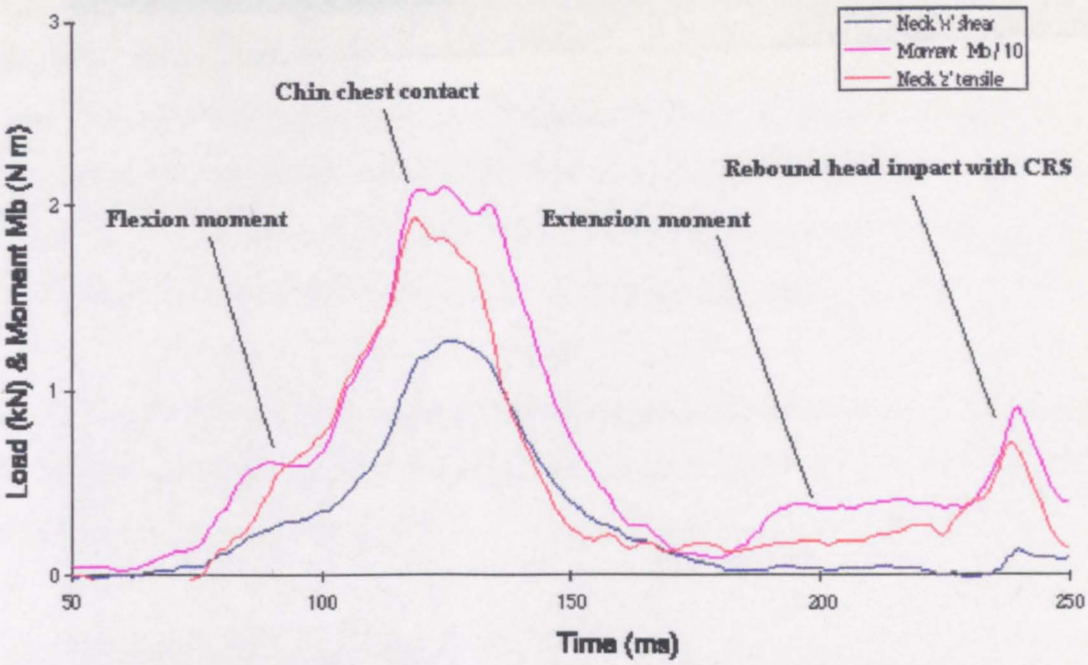


Figure 7.6 Typical Neck loads observed in a P3/4 manikin when subjected to a 50 km/h impact in a conventional belt retained CRS (T3634)

- Fx (peak) 1.27 kN Fx (30 ms) 0.7 kN
- Fz (peak) 1.92 kN Fz (30 ms) 1.12 kN
- Mb (flexion) 6.2 N m Mb (extension) 4.0 N m
- Peak Mb at chin chest contact 20.9 N m
- Chest resultant (3 ms) 44 g
- Head resultant (3 ms) 66 g
- Head excursion 543 mm

7.2.3. Torso injury criteria

Since the chest of the child is so flexible any measure of injury must consider the potential for rib fracture and for injury due to compression. According to Lau and Viano 1986 [7.10] chest compression velocity is important, and hence, thorax injury criterion will include both acceleration and a deflexion or velocity limit. However, the manikin employed in the current ECE R44 03 certification tests is from TNO P range, these are simple devices with extremely stiff chests, and no measurement of thorax deflection or velocity is possible. For this reason a resultant acceleration of <55 g at the chest centre of mass is the only assessment required by the European R44 standard. Even then, this value is considered conservative, Stürtz (1980) [7.11] reports that a deceleration limit of 55 g offers "complete protection against irreversible injuries".

8. APPROVAL STANDARDS

The approval standards upon which the evaluations made in this thesis are based are primarily those currently in force in Europe, ECE R44 (Economic Commission for Europe Regulation No 44) amendment 03. This standard however does not include a dynamic side impact evaluation, so the New Zealand side impact procedure was employed.

However approval standards affecting the child occupants of vehicles are not confined to CRS. Restraints operate as part of a system, the primary component of which is the vehicle in which the occupant is secured.

8.1. Vehicle approval standards

Until September 1998, vehicles sold in the UK were required to meet only very limited frontal impact requirements. ECE regulation 12 [4.1] defines a distributed frontal impact at 50 km/h, the acceptance requirement being defined with respect to steering wheel moment, and hence driver survival space.

At the end of September 1998, two new Directives of the European Parliament and Council, Directives 96/97/EC [4.2] and 97/27/EC [4.3], were enacted. These Directives refer to the protection of occupants of motor vehicles for all new European Community vehicle type approvals. These new standards are summarised below.

Directive 96/79/EC [4.2] **Frontal impact requirement**

> This test consists of an <u>offset frontal</u> impact with a deformable barrier (40% overlap) at <u>56 km/h</u>. The front outboard seats are equipped with comprehensively instrumented manikins, enabling determination of a number of injury and motion criteria all of which have limits specified. Specifications include head performance criteria, neck injury criteria, neck bending moment criteria, thorax compression criteria, thorax viscous criteria, femur force criteria, tibia compression force criteria, tibia index requirements and knee movement requirements.

Additionally, various vehicle criteria must be met with respect to doors and integrity.

Directive 96/27/EC[4.3] Side impact

This new test consists of a single, central perpendicular impact on the drivers side by a deformable barrier of mass 950 kg and travelling at 50 km/h. The driver's seat is equipped with a suitably instrumented side impact manikin, the output from which must satisfy the requirements of head performance criteria, thorax performance criteria (rib deflection criteria and soft tissue criteria), pelvis performance criteria, and abdomen performance criteria. Additional vehicle criteria must also be met.

Effect of the revised/new vehicle standards upon child occupants of vehicles

Although these new tests are aimed primarily at adult occupants using manikins for evaluation, the derived improvements in vehicle design will benefit child occupants. Both Directives will force vehicle manufacturers to design-in features to minimise the extent and effects of intrusion, a major cause of restrained child fatalities.

These acceptance criteria apply to the condition of the vehicle in-test and post-test and to input levels to an anthropomorphic device installed in a suitable position within the vehicle. The manikins to be used are more sophisticated than those used in European CRS certification to meet the limiting criteria for head, neck, thorax, abdomen, pelvis and extremities. To comply with the new side impact acceptance standard, vehicle side structures may need to be up-graded and indirectly reduce the injury risk of child occupants in these types of accident. When further supplemented by the CRS itself, this must enhance child safety.

8.2. National and International Standards Applicable to Child Restraints

Various legislative requirements affecting the design and performance of CRS apply world-wide and have led to the introduction of national acceptance standards which must be met before any CRS product can be sold within the applicable territories. The standards may differ in detail but all attempt to specify minimum design, performance and durability requirements that are to be met.

8.2.1. National standards

BS 3254 Part 2 1988	BRITISH STANDARD. Seat belt assemblies for motor vehicles. Part 2. Specification for restraining devices for children-1988.
BS 3254 Part 2 1992	BRITISH STANDARD. Seat belt assemblies for motor vehicles. Part 2. Specification for restraining devices for children-1991.
FMVSS 213	FEDERAL MOTOR VEHICLE SAFETY STANDARD 213. (USA) Child restraint systems.-1990 Edition.
CMVSS 213	CANADIAN MOTOR VEHICLE SAFETY STANDARD 213
JIS D 0401 1990	JAPANESE INDUSTRIAL STANDARD. Child restraints for automobiles-1990.
AS 1754 1989	AUSTRALIAN STANDARD 1754-1989. Child restraint systems for use in motor vehicles. Part 1-General requirements. Part 4-Type B child restraints (forward facing chair with harness) AS 3629-1989 is referenced for testing procedure.
NZS 5411 1991	NEW ZEALAND STANDARD 5411-1991. Specification for Child Restraining Devices in Motor Vehicles-1991.

8.2.2. International standards

ECE R44 03	ECE Regulation 44 Amendment 03-(Consolidated version-1995) Uniform Provisions concerning the approval of restraining devices for child occupants of power-driven vehicles (Child Restraints)

ECE R44 has been accepted by most European states which permits the sale of complying products in any participating state. Products can be tested at any approved test house in any of the participating countries and identified by a national 'E number' (see Appendix 6 for details). Compliance will entitle the product to an approval certificate valid in all the participating states.

ECE R44 for CRS is the standard used for most of the dynamic testing conducted in the course of this research. However, side impact tests are conducted to the New Zealand standard 5411-1991(described elsewhere) since there is no side impact requirement in ECE R44.

The salient requirements and tests defined in ECE R44 [2.1] for dynamic testing are described below. However the standard defines far more than just the dynamic impact requirements, addressing the static performance, durability, flammability and toxicity of materials, as well as the installation requirements for universal devices and the quality of instructions and labelling.

Also included in the following section is a description of the side impact element of the 1991 New Zealand standard NZS 5411-1991[2.2], since it is employed in certain sections of the following chapters.

8.3 Standards forming a basis of testing in the following chapters

8.3.1 ECE R44 03

Frontal impact requirements of ECE R44 03

The frontal impact requirements can be evaluated either in dynamic vehicle barrier tests, or with a reproducible rail guided test sled using anthropomorphic test devices (ATD's) to represent occupants of a size and mass appropriate to the CRS under evaluation. These tests specify an impact velocity between 48-50 km/h and a deceleration pulse between 20 g-28 g peak and a sled stopping distance of 650 mm +/- 50 mm (see Figure 8.1).

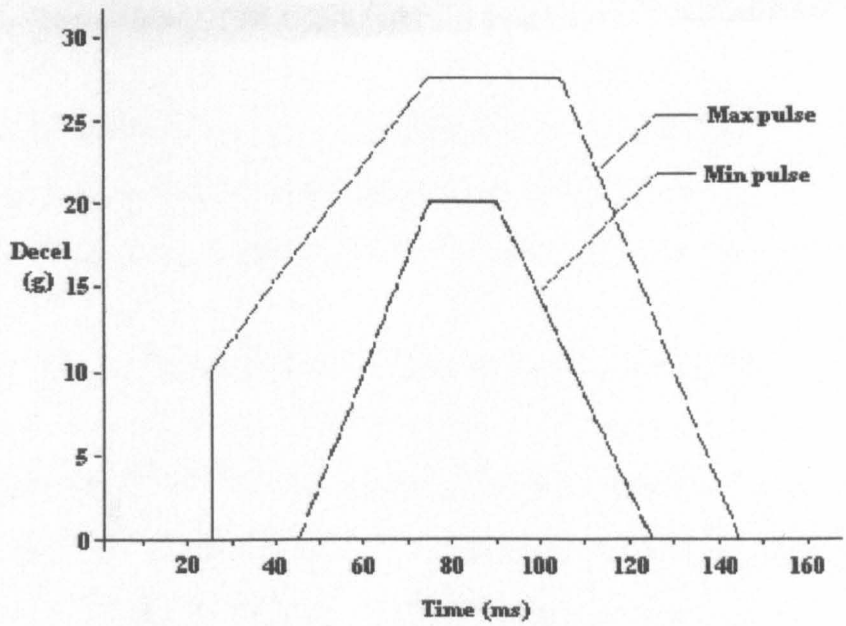


Figure 8.1 Sled deceleration pulse envelope [2.1]

When subjected to the frontal impact test described using the standard seat/cushion and a standard length of belt (locked reel for lap/diagonal tests), the following criteria must be satisfied:

- A maximum ATD head excursion of 550 mm ahead of and 800 mm above the vehicle seat cushion reference (CR) point. This is for forward facing CRS but rear facing devices have different horizontal envelope requirements depending on design.

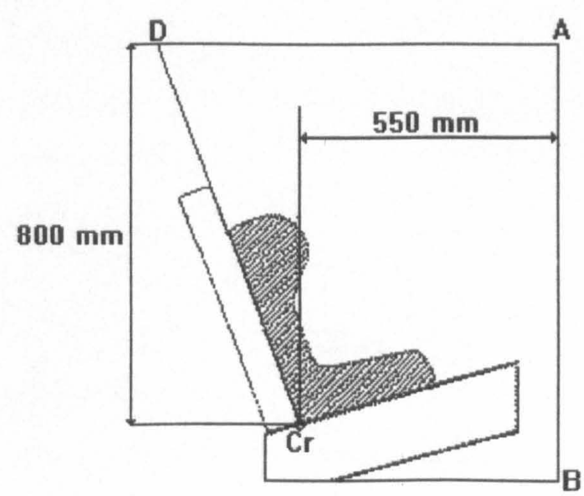


Figure 8.2 Definition of CR point [2.1]

- A maximum ATD resultant chest deceleration of 55 g.
- A maximum ATD chest deceleration in the 'z' direction (chest towards head) of 30 g.

Vehicle roll over requirements of ECE R44 03

The amendment 03 of ECE R44 details requirements for a simulated roll over test for longitudinal and lateral rolls on a prescribed fixture at a specific angular velocity. During this test the ATD's head must remain within defined excursion limits.

Side impact requirements of ECE R44 03

At present no mandatory requirement for CRS side impact performance has been evolved. However there are proposals to formulate such a test (refer to Chapter 13 for details of initial development tests to support a possible future amendment to ECE R44)..

Rear impact requirement of ECE R44 03 (Rear Facing CRS only)

An impact velocity between 30-32 km/h is required with a deceleration pulse between 14-21 g peak and a sled stopping distance of $275^{+/-}$ 20 mm. Acceleration acceptance criteria are similar to that specified for frontal impacts whilst the manikins head must not pass behind the plane Cr-D of the test bench, shown in figure 8.2 above.

8.3.2 New Zealand standard NZS 5411:1991 : Side impact requirements

The test is conducted in a sideways direction at an impact velocity of 32 km/h during which the sled deceleration shall exceed 14 g for at least 15 ms but shall not exceed 20 g. The period during which the deceleration exceeds 2 g shall not exceed 90 ms. Performance is based on the deceleration loads and excursion of the manikin.

8.4. Anthropomorphic Test Devices

Manikins or anthropomorphic test devices are produced to represent the human for test purposes. All the CRS standards specify a manikin to be used for the test, however, they may vary considerably in both complexity, biofidelity and cost. The manikins specified for the European acceptance standard ECE R44 are from the TNO range, mainly the older less complex 'P' range, P¾, P3, P6 and P10 in addition to a simple new born device. These manikins have recently been supplemented by a P1½. Only manikins specified by ECE R44 are used in this research, including those tests to the New Zealand standard although that standard calls for a different manikin.

8.5 Summary of standards being used in the UK

UK manufacturers have the option of certifying to either British Standard BS 3254 (part 2), or to ECE R44 03. The standards are similar and are updated, as necessary, to reflect changes in vehicle design.

Currently UK CRS manufacturers are certifying their products to ECE R44 to take advantage of the European market. All CRS are required to be certified to the latest standard and conformity to amendment 03 was mandatory for new products from September 1996.

The fundamental requirements of this revised standard are the dynamic performance demands, the salient points of which have been previously described.

9. DYNAMIC IMPACT TEST REGIMES/SIMULATIONS

The efficacy of performance of CRS may only be judged in road accidents, with child occupants of the appropriate age. This is possible only if there are sufficient in use and sufficient number of them to appear in accident statistics. Because we have relatively few restrained children in impacts, the reliability of any data such can be not only limited but retrospective.

There is an imperative, therefore, to simulate vehicle accidents and to predict the performance of restraint systems. This is achieved by measuring the impact deceleration induced loads on the vehicle, restraint and restrained occupant to make an assessment of potential occupant injury and mechanisms.

CRS are designed to channel the loads induced by rapid deceleration along predetermined load paths to the structure of a vehicle whilst keeping the loading on the occupant within tolerable levels.

Whilst the strength of components and assemblies may be evaluated by static testing, only dynamic testing reproduces the occupant kinematics and the reaction of restraint systems to loading, found during real road accidents.

Dynamic simulations of an accident event may be :-

- Full scale vehicle testing.
- Dynamic sled testing.
- Mathematical modelling.

In accident simulation the human surrogate is usually a mechanical anthropomorphic device and occasionally a cadaver or, less often, an anaesthetised animal. The use of the last two pose ethical problems with sections of the public.

Cadaver

A cadaver is the most realistic surrogate for a live occupant, but it is difficult to obtain child subjects. Cadavers may vary considerably in size and mass, and do not have the same physiology as a live human, (e.g. the absence of blood pressure and muscle tone), but do have the benefit of being examined post-test for injuries.

Animal surrogate

The animal surrogate (primate or porcine) is alive during the test but does not possess the same body proportions or have the same detailed anatomy as a human.

Mechanical surrogate (ATD or manikin)

The most widely employed surrogate occupant for CRS evaluation is the mechanical ATD or manikin. These devices may represent occupants of any size/mass and commonly a 50th%ile in each of the required ages. Manikins vary in complexity and present many advantages, particularly repeatably reproducible response to input. However they are not entirely bio-fidelic. It is in improving the response of manikins that the use of cadaveric subjects may best be justified.

It is for these reasons that CRS compliance and certification test procedures specify the use of manikins notwithstanding their disadvantages.

9.1. Full scale vehicle testing

Full scale vehicle testing is the most realistic of the crash simulation techniques but the cost makes it prohibitive for CRS evaluation alone, particularly if repetitive testing is required. Vehicle testing is more commonly employed to assess the crash-worthiness of the vehicle itself, the adult restraint system within it or the total restraint package, that may include a CRS. Tests involving whole vehicles may take the form of vehicle to vehicle impacts, vehicle to rigid/deformable barrier impacts, or vehicle to movable barrier impacts, depending upon the parameters being assessed.

The vehicles, or the movable barrier, are commonly accelerated to impact velocity by means of a winch up to the point of impact. Vehicles usually contain various occupant configurations to obtain maximum data per unit cost. The vehicle or vehicles and the manikins will be fully instrumented and the dynamic event recorded on film by cameras mounted internally and externally for post test motion analysis.

Although potentially the most representative of the crash simulation techniques, the vehicles behaving as they would in a real accident, there are problems with repeatability and variable impact performance characteristics. A CRS satisfactorily tested in one vehicle may not perform adequately in another, due to a number of factors ranging from interior dimensions to vehicle condition. For greater repeatability and lower cost, CRS sled testing is employed.

9.2. Sled Impact Testing

Sled testing is the defined approval regime for most CRS and adult restraint systems most widely employed. Due to its control and repeatability of velocity, deceleration and impact and lower cost, it is also an appropriate test method for the research and development of new products. An exception is vehicle specific CRS, when full scale vehicle or vehicle body shell sled tests are necessary.

The reproduction of a sled mounted vehicle impact is sensitive to sled characteristics. Sled acceleration and deceleration are uni-axial but in-vehicle events are complex with six degrees of freedom. In addition, the uni-axial deceleration pulse of the sled is an over simplification of real vehicle deceleration pulses.

9.2.1. RSEL sled impact facility

The reported dynamic test simulation programme was conducted at the Middlesex University Road Safety Engineering Laboratory (RSEL). The impact test facility was based on that used by the British Standards Institution (BSI) for certification testing to British and European (ECE) standards.

See Appendix 7 for full details of test facility and equipment.

9.3. Mathematical Modelling

Mathematical modelling or mathematical crash victim simulation (CVS) can range from a simple single mass spring model executed on paper to a complex multi-body or dynamic finite element model comprising many thousand elements requiring the use of a computer to obtain the output. A number of software packages are commercially available, 2D and 3D, which allow the user to predict with a degree of accuracy the outcome an object or occupant might expect to realise in an impact scenario, given a known set of input data. One such piece of software, widely used in industry is the MADYMO (MAthematical DYnamic MOdel) package, supplied by TNO of Holland. This package in its 3D form was acquired by the university, and employed by the writer in the later stages of this work to model some of the tests detailed in this document, allowing furtherance of the research at a later date. In addition to the basic MADYMO package, a complimentary package called EASi-MAD was also employed, which simplifies the data input process to the MADYMO data files.

The advantage offered by mathematical modelling over full scale tests are clear, once constructed, the mathematical model can be run rapidly, parameters changed, and the runs repeated. This should lead to lower costs evaluations, especially if repetitive 'parametric' type studies are being conducted as the model once constructed can be very easily modified. There are also advantages in that no experimental error will exist in the analysis. Hence, even very small changes in the output will be clearly identified, which with full scale testing may not be clear. Finally, mathematical modelling offers the possibility of discrete changes to input data, something which may not be so simple with real tests.

There are however potential disadvantages with the modelling of anything. A model will only predict outcomes based on the data and parameters within the model. Anything omitted or not considered, will not, however small or large its effect, be reflected in the output. Likewise, and inherent with all models, they are simplifications of the real situation, and will contain assumptions, correct or not. Such simplifications introduce modelling errors, which must be considered when reviewing results. It is essential to model a known outcome first to validate the model, giving greater confidence in subsequent modified versions of the model.

10. PERFORMANCE OF CURRENT CRS SYSTEM TYPES

Having reviewed CRS types (chapter 6) and the criteria/means by which they are dynamically assessed (chapters 8 and 9), it is now appropriate to discuss the dynamic performance and limitations of existing CRS types and their immediate predecessors.

10.1. Existing Issues

In (1994/1995), the performance of existing adult belt retained CRS was considered of concern because of changes in the adult restraint geometry of modern family vehicles. These changes resulted in a deterioration in the performance of adult belt restrained CRS through excessive head excursion attributable to vehicle 'downsizing' and changes to belt anchorage points. Head injury is the most frequent injury type detailed in restrained fatalities report (Rattenbury S J, Gloyns P F [3.6]), and contact between an intruding structure and a restrained child is highlighted in many of the cases. The increased head excursion in modern cars was, therefore, of considerable concern.

At this time, there were many CRS certified to ECE R44 02 in use but this standard was inappropriate with newer vehicle types with modern automatic retractor lap and diagonal belts. The effect of this combination of older standard and newer vehicles artificially enhanced the CRS performance compared with the revised ECE R44 03 standard which reflected a more modern car.

10.2. ECE R44 02 Approved Product Tested to ECE R44 03 Dynamic Requirements

Forward facing framed Group 1 devices demonstrated particular sensitivity to the anchorage and belt changes detailed in the revised R44 03 standard when subjected to the frontal impact requirements. The test detailed below is of a typical forward facing framed ECE R44 02 CRS with a lap and diagonal adult belt attachment, tested to R44 03.

Test 2890

Head excursion beyond CR point	Peak chest resultant acceleration (3 ms)	Chest 'z' component tensile/compressive (3 ms)	Peak head resultant acceleration (3 ms)
(mm)	(g)	(g)	(g)
692	41.4	26.8 / 22.8	77.7

Figure 10.1 Response of R44 02 approved Group 1 framed CRS tested to R44 03 in frontal impact

Head excursion at 692 mm ahead of the CR point (see Figure 8.2) of the test seat is 25% greater than the acceptance limit of 550 mm whilst other criteria are unaffected or improved. Excessive head excursion occurred in all tests with forward facing framed R44 02 approved Group 1 CRS evaluated to the R44 03 dynamic requirements.

Rear facing Group 0 infant carriers deploying greater lengths of the adult belt than the framed Group 1 forward facing CRS, were found to be much less sensitive to the adult restraint changes. The effective angle of the belt makes the system less sensitive to anchor position. Similarly Group 2 and 3 booster seat dynamic performance was largely unaffected by the anchor and belt amendments.

Rear impact dynamic performance of all rear facing restraints was also largely unaffected by the amendment to the standard. There were/are no dynamic side impact requirements in either R44 02 or 03.

It should be noted that detail changes in Amendment 03 led to the revision of a number of CRS features, such as belt lock off, on all CRS types. In particular, the issue of buckle crunching (tendency for the adult seat belt buckle to lie on the frame of a group 1 CRS giving the potential for failure due to the loading in bending) on framed CRS was addressed and produced significant changes to loading positions on a CRS frame.

10.3. Development of conventional belt retained group 1 CRS to conform with the frontal impact requirements of ECE R44 03

It was the Group 1 forward facing CRS that required significant development to meet the revised frontal impact dynamic requirements of ECE R44 03.

Forward facing Group 1 CRS conventionally retained by an adult belt react in one of two ways to a frontal impact. Those with a tubular frame tend to rotate about the front tube or, if fitted with a big foot tend to slide along the test seat cushion. The outcome depends on the position of the centre of mass of occupant and/or CRS with respect to the adult belt attachments and will to an extent influence the tendency for the occupant's head to travel forward.

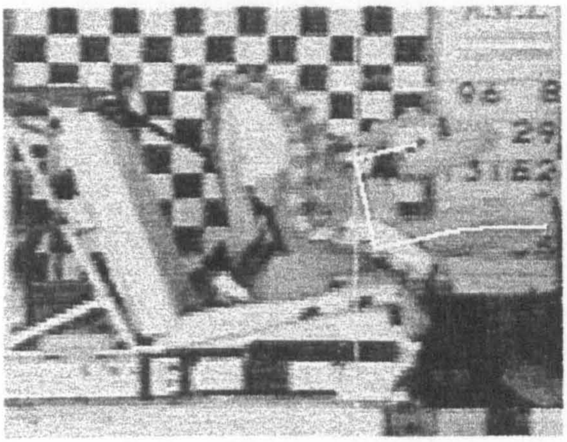


Figure 10.2 Conventional Group 1 CRS response (MURSEL test No 3162)

Minimising the resulting head excursion is crucial, and in attempting to do so a number of fundamental characteristics were highlighted, namely:

- Most Group 1 forward facing CRS can be installed with either a retractor lap and diagonal or static adult lap belt. Further, many offer a recline feature so that a child may be in a supine position during travel. It is apparent that simple lap belt attachment is the worst case set up for this CRS type with respect to head excursion when in the most reclined position.

  The deployment of a lap belt alone to retain the CRS is commonly worse than using a lap and diagonal belt because the diagonal section acts as an asymmetric top tether. However, observation that greater recline angle of the occupant can increase ultimate head excursion was unexpected and the results of an investigation into the effect of recline angle are reported chapter 12.

- The material specification for CRS is important. Steel framed CRS required shell and frame material of sufficiently high yield stress for minimum elastic deformation under load.

- The geometry of the seat with respect to head and shoulder position is also important. Initially the further back the head and shoulders, the greater the forward movement possible before exceeding the forward limit.

- It was evident that the greater the angle of recline during an impact the more the upper torso tends to rotate within the upper harness.

- The introduction of Group 1 forward facing framed products complying with ECE R44 03 was accompanied with shoulder pads attached by webbing to the upper shell. Testing confirmed that frictional contact between occupant and shoulder pads limited occupant rotation and reduced head excursion by at least 25 mm. The benefit of shoulder pads is addressed later (see 10.7).

Manufacturers are now modifying the structure and geometry of the Group 1 forward facing CRS so that occupant forward movement is led by the feet rather than the head. Figure 10.3 tracks occupant forward movement to peak excursion in marked contrast to the head first movement shown in Figure 10.2.

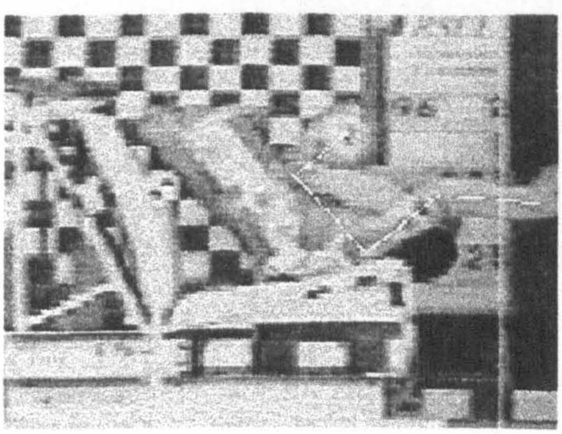


Figure 10.3 Recently developed blow moulded CRS design (MURSEL test No 3003)

10.4. Abdominal Shield Booster Seat Performance

Abdominal shield booster seat devices (see figure 6.8) are common in North America but, tested using a P3 manikin, they did not comply with the dynamic requirements of ECE R44 in the following respects:

- Vertical head excursion of 806 mm was marginally in excess of the 800 mm limit.

- Peak chest resultant deceleration (3 ms filtered) was 10.4 g above the maximum acceptance limit of 55 g.

Furthermore, on rebound the manikin was seen to be projected upwards and backwards and only the inflexiblity of the manikin's leg joints prevented complete ejection. The abdominal shield was damaged as a result of contact with the manikin's thorax and abdomen although no measurements of abdominal load was possible. Full details of the testing and results can be found in report [10.1]

10.5. ECE R44 03 group 1 CRS Designs and Issues Arising

Buckle crunching

Ill fitting or other misuse of CRS has been reported as over 80% in recent studies (Chapter 3). The number approved to ECE R44 03 is unclear, but anecdotal evidence suggests buckle crunching was still a major problem with many Group 1 'universal' CRS complying with the R44 03 '150 mm minimum' distance between CR point and load bearing point on the CRS.

Many of these ECE R44 03 CRS can be re-installed using an alternative routing, given in the instructions, which met the dynamic requirements of the standard but do not meet the approval requirements with respect to the '150 mm minimum'. Although this alternative routing locates the buckle underneath the CRS it can prove a satisfactory method of installation.

It is recommended that any future amendments to the R44 standard should recognise the buckle crunching concerns and for 'universal' devices incorporate a mandatory alternative route for CRS such that any appropriate length of buckle can be accommodated.

10.6 Performance of current CRS types

All ECE R44 03 certified CRS must meet the dynamic requirements of that standard. However, CRS type and occupant size/mass affects deceleration and loading levels. The following illustrates the effect of these factors on TNO P3 and P3/4 manikins when evaluated to ECE R44 03 in frontal impacts using restraint types legally available/possible in the UK (Figure 10.4).

The following table details the current UK legislative requirements with respect to CRS usage, applicable to children represented by the above manikins.

Occupant	Front seating position	Rear seating position
0-2 (inclusive) years old	An appropriate CRS must be used	An appropriate CRS must be used if available
3-11 (inclusive) years old and under 1.5 m in height	An appropriate CRS must be used if available, if not an adult belt must be used	An appropriate CRS must be used if available, if not an adult belt must be used if available

Figure 10.4 UK legal requirements for CRS usage

UK legislation permits young children to be restrained by adult belt systems and from three years old an adult belt alone can be used if no suitable CRS is available. Further, nine month old children may be restrained in Group 1 CRS of the booster seat type using adult belts. Manikin response restrained under both systems tested to ECE R44 is given below (Figure 10.5.), the booster seat employed was typical of those on the market today, certified to R44 03 for Group 1 application.

Restraint system	Adult lap and diagonal belt	Adult lap and diagonal belt + booster seat
Test No	3589	3632
Manikin	P3	P3/4
Impact vel (km/h)	49	49
Peak decelerations (g)		
Head resultant deceleration 3 ms	81	44
Chest resultant deceleration 3 ms	64	42
Chest 'Z' acceleration chest to head 3 ms	34	5
Chest 'Z' acceleration chest from head 3 ms	17	17
Peak excursion (mm)		
Head Excursion	422	450
Neck loads		
Peak tensile 'z' [30 ms] (kN)	2.7 [1.6]	1.2 [0.7]
Peak shear 'x' [30 ms] (kN)	2.3 [1.3]	0.5 [0.3]
Peak bending moment at chin chest contact (Nm)	41	12

Figure 10.5 response of adult belt retained TNO 'P' range child manikins

The P3 manikin restrained by adult lap and diagonal belts (T3589) failed to meet the deceleration requirements of ECE R44 in two respects. Resultant chest acceleration was 16% in excess of the 55 g limit and chest-to-head deceleration (spine compression) exceeds the 30 g limit by 13%. However, the peak head excursion of 422 mm is well within the 550 mm limit. Analysis of accelerometer traces (see figure 10.6 below) for the single belt system show, confirmed by video film, the sled well into its deceleration pulse before the occupant begins to decelerate. The rapid rise in occupant chest response, primarily a function of the 'x' component suggests that the adult belt may be stiffer than necessary for the P3 (15 kg) manikin. Further, the rapid rise of the chest 'z' (compressive) component indicates that the belt geometry may result in forcing the manikin into the test seat.

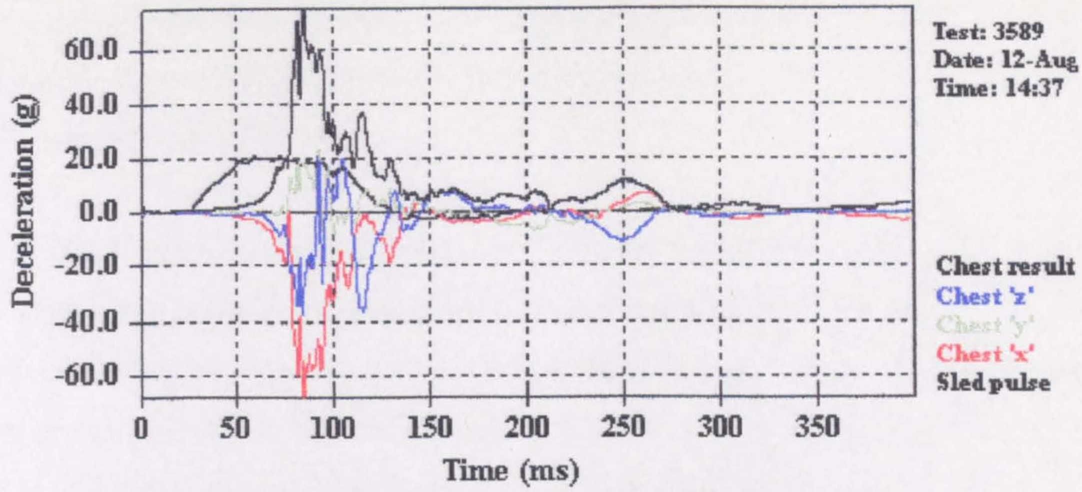


Figure 10.6 Chest deceleration, P3 manikin in adult lap and diagonal belt only, frontal impact

Head acceleration response (figure 10.7 below), is led to a large extent by the 'x' component (implying neck shear occurs), rapidly superseded by the 'z' component as the major factor (implying neck tension occurs) due to rapid head rotation about the neck and its atlas joint.

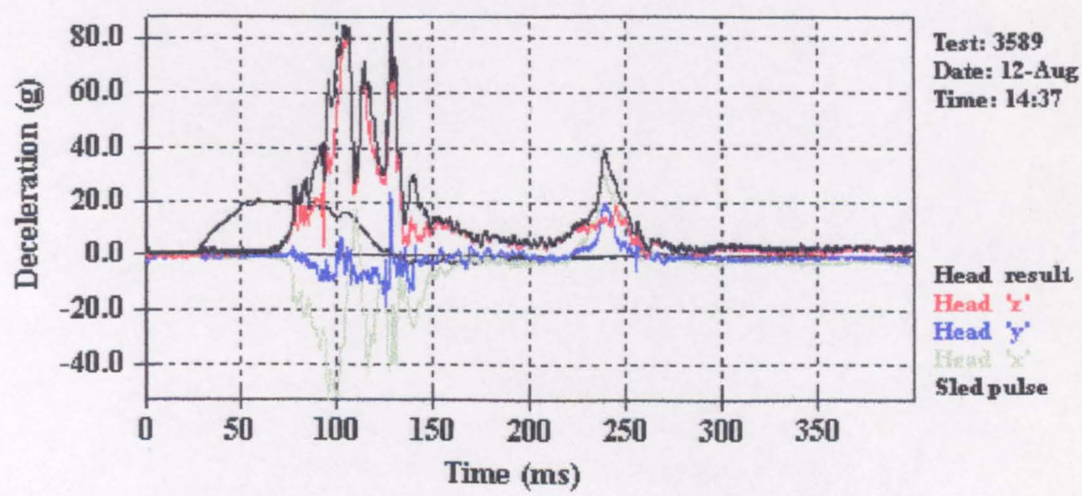


Figure 10.7 Head deceleration, P3 manikin in adult lap and diagonal belt only, frontal impact

Neck loads were recorded during this test but no generally accepted limits are relevant due to the nature of the TNO 'P' manikin's neck construction with its 1 g atlas joint. The neck loads during deceleration were high compared with 'P3' CRS tests detailed in this section. Nevertheless it is proposed to assume these to be baseline results to compare with other CRS tests results on the same size manikin. A possible explanation for the high neck loads is proximity of the neck to the diagonal section of the adult belt about which the head may pivot. However, this was unconfirmed by video film.

There was no evidence of 'roll out' of the upper torso, rotating over the top of the diagonal belt section and no disengagement of a restrained arm prior to peak head excursion (a test failure as defined by ECE R44).

For the 'P3/4' (9 kg) test in the booster seat (T3632) all applicable parameters were within the requirements of R44, the major chest deceleration being the 'x' component with a much lower 'z' component. The video film, however, showed the manikin as starting to 'roll out' of the diagonal section of the belt although the arm had not completely disengaged prior to peak head excursion and this may explain the relatively low value of resultant head acceleration and the greater overall head excursion. If roll-out occurs the manikin's head will be projected diagonally towards the side of the vehicle. The position of the diagonal section of the adult belt prior to impact will to a great extent be reflected in this tendency, and this is an important factor in the design of such devices.

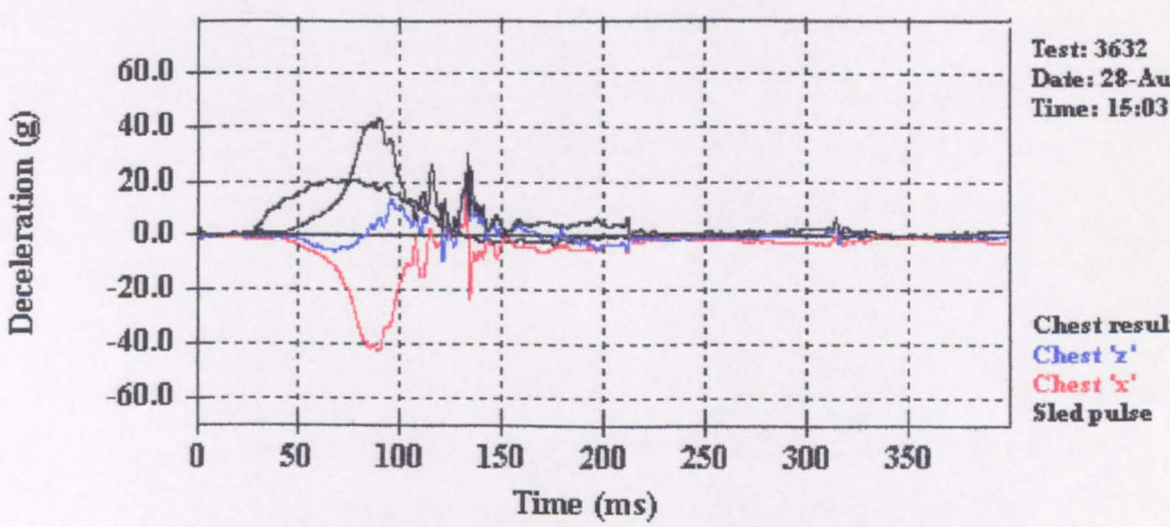


Figure 10.8. Chest deceleration, P3/4 manikin in Booster seat, adult lap and diagonal belt, frontal impact

Whilst the neck shear and tensile loads induced in this manikin can only be used for comparative purposes, both the peak and 30 ms values were significantly lower than values quoted by Janssen [7.3]. Janssen, using a TNO 'P3/4' manikin tested in a forward facing group 1 CRS in an attempt to reconstruct a neck injury accident, values of shear and tensile were reported as follows:-

- F'z' = 1.55 kN (1.14 kN 30 ms)
- F' x' = 0.83 kN (0.62 kN 30 ms)

The comparatively low values seen in the booster seat test may again possibly be affected by the 'roll out' tendency.

The effect of a booster seat on 'P3' response

The 'roll out' tendency observed in the above R44 sled test is not confined to the P3/4 manikin on a R44 03 approved booster cushion. By moving the diagonal belt away from the neck the 'P3' manikin also promotes 'roll out' and, again, peak head excursion was reached just before the arm become completely disengaged. All other R44 approval parameters were satisfied (Figure 10.9 below).

Restraint system	**Adult lap and diagonal belt + booster seat**
Test No	3588
Manikin	P3
Impact vel (km/h)	49
Peak decelerations (g)	
Head resultant deceleration 3 ms	59
Chest resultant deceleration 3 ms	54
Chest 'Z' acceleration chest to head 3 ms	18
Chest 'Z' acceleration chest from head 3 ms	12
Peak excursion (mm)	
Head Excursion	472
Neck loads	
Peak tensile 'z' [30 ms] (kN)	1.9 [0.9]
Peak shear 'x' [30 ms] (kN)	1.3 [0.5]
Peak bending moment at chin chest contact (N m)	28

Figure 10.9 response of adult belt retained TNO 'P3' child manikin on booster

The tendency to 'roll out' of the diagonal on the R44 test bench has also been observed in 'P6' and 'P10' booster cushion tests and the problem is recognised within the standard. There is dispensation for the 'P10' manikin that allows the CRS to be moved towards the pillar loop by up to 75 mm. The problem is a function of the restraint geometry of the R44 standard anchorages. The pillar loop feature is more characteristic of square sided type vehicle (such as a Land Rover) than conventional vehicles with significant tumble home in the upper roof structure. However the logic of allowing repositioning of the pillar loop for only one age group of manikin is difficult to comprehend.

It is evident that booster seat type CRS can benefit young occupants, but it must be recognised that they do have disadvantages, particularly the tendency for occupant roll out over the diagonal section of the belt. Although all the approved products have some form of guide in-built to direct the diagonal belt to a suitable position on the child's chest, these are designed for the specific 50th%ile manikin used in the tests. In reality, the use of such guides can be less than optimal, and it must be recognised that children rarely sit still with the shoulder belt maintained in the ideal position. There is scope for future research into the real effectiveness of such devices.

The effect of harness type CRS (framed or moulded) on manikin response

The forward facing framed or moulded CRS incorporating a separate harness is an alternative to the adult belt as the sole primary restraining medium for children in the age Group 9 months to 3-4 years (9-15 kg).
The dynamic performance of two typical R44 03 approved products secured by an adult lap and diagonal belt is given below (Figure 10.10)

Harness type restraints have a number of advantages over the lap and diagonal belt in a frontal impact. Firstly, they are symmetrical, the occupant's trajectory during an impact will be parallel to the centre line of the vehicle (assuming the vehicle impact is not oblique). Secondly the stiffness of the system can be more attuned to the occupants mass and thirdly the harness can be so designed to transfer loads to desired points of the body, with a crotch strap preventing submarining. It will be observed that for a given CRS the occupant mass affects ultimate head excursion and deceleration levels, whilst the deceleration level of the chest, with the unrestrained head attached affects neck loading.

Restraint system	Moulded Group 1 CRS	Moulded Group 1 CRS	Steel framed Group 1 CRS
Test No	3619	3578	3576
Manikin	P3/4	P3	P3
Impact vel (km/h)	49	50	49
Peak decelerations (g)			
Head resultant deceleration 3 ms	66	61	81
Chest resultant deceleration 3 ms	52	50	52
Chest 'Z' acceleration chest to head 3 ms	12	15	13
Chest 'Z' acceleration chest from head 3 ms	11	16	31
Peak excursion (mm)			
Head Excursion	514	607	522
Neck loads			
Peak tensile 'z' [30 ms] (kN)	1.8 [1.2]	2.2 [1.2]	2.9 [1.8]
Peak shear 'x' [30 ms] (kN)	1.3 [0.8]	1.5 [0.7]	2.4 [1.6]
Peak bending moment at chin chest contact (N m)	24	33	46

Figure 10.10 Response of TNO 'P3/4' and' P3' manikins in forward facing ECE R44 03 approved Group 1 CRS

Both the CRS shown above are approved to the latest amendment of R44, (03), indicating that they conform with the dynamic requirements using both the largest and smallest appropriate manikins (P3 and P3/4). It will be noted that as tested during this research exercise the moulded CRS failed to meet the R44 head excursions requirements in this test (T3578). This is not an unusual outcome for this particular CRS type, as in a total of five separate tests conducted on this particular model of CRS, not once have the head excursion requirements been met. It must be emphasised that the test rig and data collection equipment with respect to head excursion at Middlesex University were identical to that used by BSI for certification at their Hemel Hempstead site. Conformation of this is that the steel framed CRS shown in the above data was tested at both sites with virtually identical results.

What does stand out from the above tests with the 'P3' manikin is the increased neck loads that were induced in the manikin in the steel framed CRS (also the high level of chest 'z' acceleration, chest from head). The steel framed CRS has a seat base angle to the horizontal greater than the moulded CRS (both devices were in their upright configurations). Although no neck limits exist based on this manikin, and no requirement is made in the R44 certification test, the neck loading levels observed in the steel framed CRS test, with the greater seat base angle is at least as high or higher than the levels seen in the 'no CRS' (adult belt only) test (T3589).

The adult restraint used in the above comparative tests to secure the CRS to the sled was of the lap and diagonal type. Experience has shown this not to be a 'worst case' installation with respect to head excursion. Lap belt only installation, a marketing necessity, will produce a potentially 'worst case' response as the diagonal section of a belt tends to act as an asymmetric top tether.

Figure 10.11 shows the comparative effect on occupant response of lap belt attachment Vs lap and diagonal attachment for a 'P3/4' manikin.

For CRS restrained by a lap belt the head excursion was greater than with the lap and diagonal restraint. Because of this increased forward movement, overall resultant deceleration levels were less than those recorded for the lap and diagonal as were the neck loads, although that difference was small. The greater chest 'z' acceleration levels with the lap only restraint is possibly a function of greater rotation and bottoming-out of the cushion.

Restraint system	Moulded Group 1 CRS Lap and Diag affixed	Moulded Group 1 CRS Lap belt affixed
Test No	3619	3622
Manikin	P3/4	P3/4
Impact vel (km/h)	49	49
Peak decelerations (g)		
Head resultant deceleration 3 ms	66	61
Chest resultant deceleration 3 ms	52	41
Chest 'Z' acceleration chest to head 3 ms	12	16
Chest 'Z' acceleration chest from head 3 ms	11	13
Peak excursion (mm)		
Head Excursion	514	529
Neck loads		
Peak tensile 'z' [30 ms] (kN)	1.8 [1.2]	1.8 [1.0]
Peak shear 'x' [30 ms] (kN)	1.3 [0.8]	1.2 [0.7]
Peak bending moment at chin chest contact (N m)	24	23

Figure 10.11 Response of TNO 'P3/4 manikins in forward facing ECE R44 03 approved Group 1 moulded CRS Lap/Diag Vs lap belt retained

10.7 Retained shoulder pads to minimise head excursion

ECE R44 03 has driven the modification of restraint systems. The head excursion limit of 550 mm from the CR point was the critical parameter manufacturers had to satisfy after the introduction of amendment 03. This excursion limit was difficult to achieve and promoted the development of Group 1 forward facing CRS with shoulder pads attached to the upper shell. This inexpensive development has reduced manikin head excursion by some 25 mm by minimising torso rotation within the upper harness due to increased friction between the manikin and straps. Some popular UK CRS cannot satisfy this requirement without them.

Figures 10.12 to 10.14 show the performance of Group 1 forward facing moulded and steel framed CRS, ('P3/4' and 'P3' manikins) with and with out these attached shoulder pads.

Restraint system	**Moulded Group 1 CRS Lap and Diag affixed**	
Attached shoulder pads	with	with out
Test No	3619	3620
Manikin	P3/4	P3/4
Impact vel (km/h)	49	49
Peak decelerations (g)		
Head resultant deceleration 3 ms	66	60
Chest resultant deceleration 3 ms	52	48
Chest 'Z' acceleration chest to head 3 ms	12	11
Chest 'Z' acceleration chest from head 3 ms	11	9
Peak excursion (mm)		
Head Excursion	514	536
Neck loads		
Peak tensile 'z' [30 ms] (kN)	1.8 [1.2]	1.5 [1.1]
Peak shear 'x' [30 ms] (kN)	1.3 [0.8]	1.1 [0.8]
Peak bending moment at chin chest contact (N m)	24	21

Figure 10.12 Response of TNO 'P3/4 manikins in forward facing ECE R44 03 approved Group 1 moulded CRS, Lap/Diag retained, with and without attached shoulder pads

Restraint system	**Moulded Group 1 CRS Lap and Diag affixed**	
Attached shoulder pads	with	with out
Test No	3578	3580
Manikin	P3	P3
Impact vel (km/h)	50	49
Peak decelerations (g)		
Head resultant deceleration 3 ms	61	65
Chest resultant deceleration 3 ms	50	47
Chest 'Z' acceleration chest to head 3 ms	15	14
Chest 'Z' acceleration chest from head 3 ms	16	20
Peak excursion (mm)		
Head Excursion	607	642
Neck loads		
Peak tensile 'z' [30 ms] (kN)	2.2 [1.2]	2.2 [1.1]
Peak shear 'x' [30 ms] (kN)	1.5 [0.7]	1.4 [0.7]
Peak bending moment at chin chest contact (N m)	33	28

Figure 10.13 Response of TNO 'P3 manikins in forward facing ECE R44 03 approved Group 1 moulded CRS, Lap/Diag retained, with and without attached shoulder pads

Restraint system	Steel framed Group 1 CRS Lap and Diag affixed	
Attached shoulder pads	with	with out
Test No	3576	3577
Manikin	P3	P3
Impact vel (km/h)	49	49
Peak decelerations (g)		
Head resultant deceleration 3 ms	81	78
Chest resultant deceleration 3 ms	52	49
Chest 'Z' acceleration chest to head 3 ms	13	16
Chest 'Z' acceleration chest from head 3 ms	31	32
Peak excursion (mm)		
Head Excursion	522	564
Neck loads		
Peak tensile 'z' [30 ms] (kN)	2.9 [1.8]	2.8 [1.1]
Peak shear 'x' [30 ms] (kN)	2.4 [1.6]	2.1 [0.7]
Peak bending moment at chin chest contact (N m)	46	41

Figure 10.14 Response of TNO 'P3 manikins in forward facing ECE R44 03 approved Group 1 steel framed CRS, Lap/Diag retained, with and without attached shoulder pads

The effectiveness of shoulder pads in reducing manikin head excursion is clear but deceleration levels and neck loads are generally higher.

These results raise two questions as to the real effectiveness of these shoulder pad innovations. Do they offer the same advantage with a child as they do with the very stiff TNO manikin and would they offer the same advantage if the occupant/manikin were wearing thick winter clothing.

Only the question concerning dress and clothing is appropriate to this research and a limited series of tests were conducted on a well controlled CRS using the following types of clothing on a standard TNO 'P3' manikin:-

1. The standard manikin pyjama clothes.
2. 1 + Shirt and wool jumper.
3. 1 & 2 + One piece nylon padded snow suit.

The CRS used for the assessments was a rigid four point Isofix type CRS that eliminated any effect of adult belts and seat cushion (see chapter 13 for details). The seat base angle was set at a typical upright position of 30^{o}. Since the CRS used was not installed on an ECE R44 test bench a CR point based upon the position of the rear Isofix pin location was used.

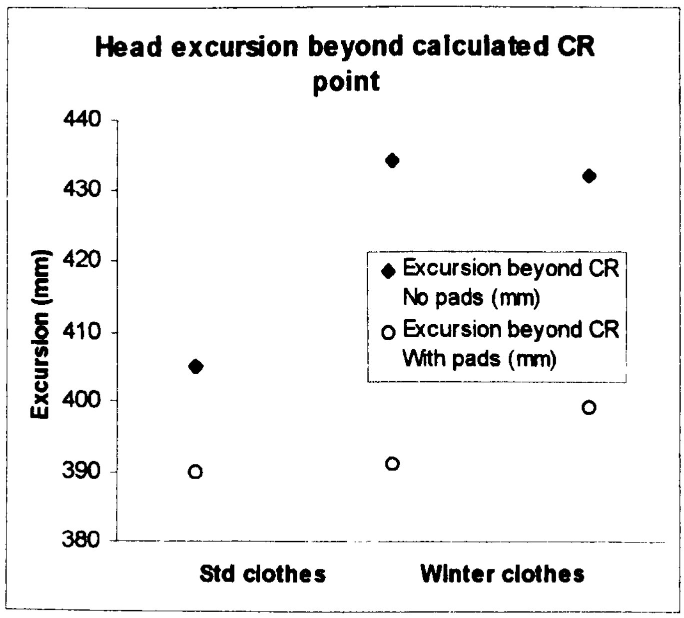


Figure 10.15 Calculated Head excursion

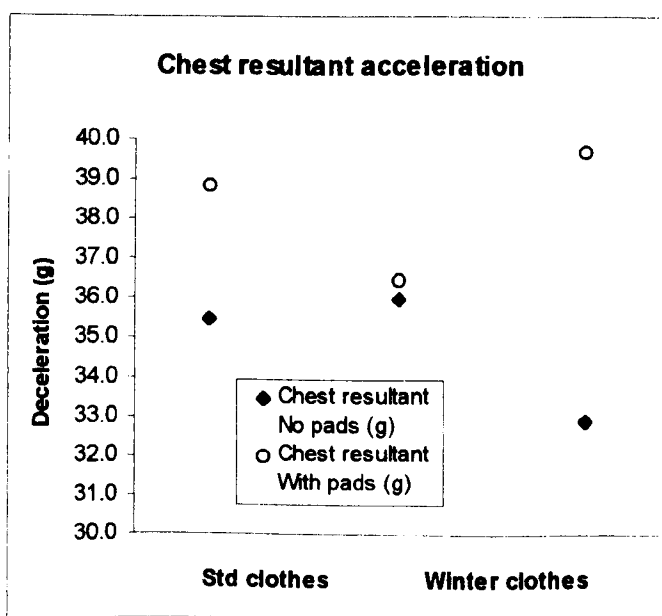


Figure 10.16 Chest resultant deceleration

The harness loads in the upper (shoulder) section were measured with and without the attached shoulder pads, and the following figure (10.17) produced.

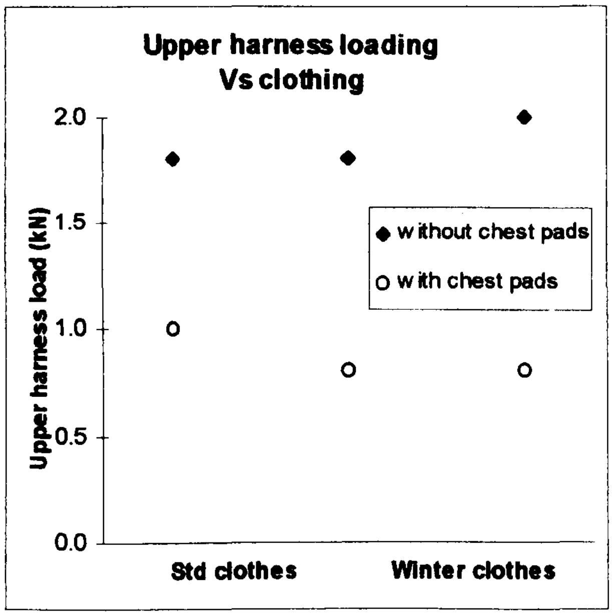


Figure 10.17 Upper harness (shoulder strap) loads

The retained shoulder pads reduced overall manikin head excursion with some correlation with chest resultant deceleration. The performance in terms of head excursion is only marginally affected by the amount of clothing on the manikin. The reduction in load seen on the upper harness section was approximately 50%, and was confirmed by a repeat test with the load cell on the shoulder pad strap. On impact this strap load peaked at 0.78 kN.

All the above tests were conducted with the CRS in its upright configuration, a later chapter of this document will address the effect of seat recline angle.

The performance of rear facing infant carriers was relatively unaffected by amendment 03 to ECE R44.

10.8. Side impact evaluation of current CRS types

No side impact evaluations were specifically conduced on current CRS types (none is required in the ECE R44 standard at present). However the following chapter detailing the performance of the proposed Isofix CRS systems does include current CRS (R44 03) as a baseline. The isofix tests include testing to the New Zealand side impact standard (NZS 5411:1991).

11. THE ISOFIX CONCEPT

A perceived major advantage of current CRS retained by the vehicle belt system is the simplicity and convenience. However, there is no single installation procedure and each CRS works optimally only if the adult belt is routed and tensioned according to the manufacturers instructions. This can result in the possibility of incorrect or poor fitting.

The main concerns are that the adult belt that attaches the CRS to the vehicle is either mis-routed or too loose. This has led to proposals for an improved CRS/vehicle interface. The proposals, entitled Isofix were co-ordinated by the International Standards Organisation with the aim of producing an international standard system for fixing CRS to vehicles. Isofix is a universal attachment concept, to be adopted by CRS and vehicle manufacturers so that new vehicles and new CRS will have compatible attachment fittings.

The concerns associated with conventional belt retained CRS may be summarised as follows:-

- Less than optimal retention/geometry constraints, inertia reel spool out and potentially high occupant excursion/deceleration levels.

- Potential for incorrect fitting due to the complexities of both the adult belt routing and operation of belt lock off devices.

- The influence of different seat cushions on both the installation and dynamic response of the child seat.

These concerns will be largely overcome with the use of dedicated CRS attachments built into the vehicle structure. The potential benefits of integrated restraints are recognised, and some manufacturers do already offer built-in child restraints although these are permanently fitted and generally suitable for only one age group (see section 6.3). The Isofix concept of latched, removable CRS is intended to offer all the benefits with none of the disadvantages.

11.1. History of the Isofix concept

The concept of a uniform dedicated attachment system for the installation of CRS into vehicles began in Sweden in 1990. The first prototype of an Isofix system was presented to the ISO Working Group on Child Restraints (ISO/TC 22/SC 12/WG1) in 1991. Subsequently, proposals were submitted for both forward and rear facing CRS. Whilst there was a variety of latching configurations, all sought to comply with the ISO specifications given in [11.1].

The ISO features are listed below:

Essential features:

1. Universal use of seating location without impairment of safety and comfort
2. Minimise misuse potential
3. Positive engagement of latch attachment
4. Low risk of partial engagement
5. Suitable for all passenger seating positions
6. Functions on folding seats
7. Suitable for all groups of CRS
8. Standardised attachment and release method
9. No additional risk to any occupants in an accident
10. Prevention of accidental release
11. Ease of use with minimal instructions
12. Meet current safety standards
13. Independent of vehicle seat cushion
14. No negative effect on handling CRS

Desirable features

1. Simple to use, low cost, cost effective
2. Improved CRS stability in normal use
3. Improved dynamic performance
4. Minimum mass and strength
5. Fixed anchors in vehicle
6. Allow for use with air bag without increased risk
7. Meet future requirement in side impact and roll over
8. Acceptable levels of comfort
9. Suitable for non Isofix seating position
10. Easy release of Isofix CRS after accident

Bonus features

1. Possibility of use in other vehicle types
2. Possibility to install in existing vehicles

Some of the early rear and forward facing configurations are shown below [11.1]:-

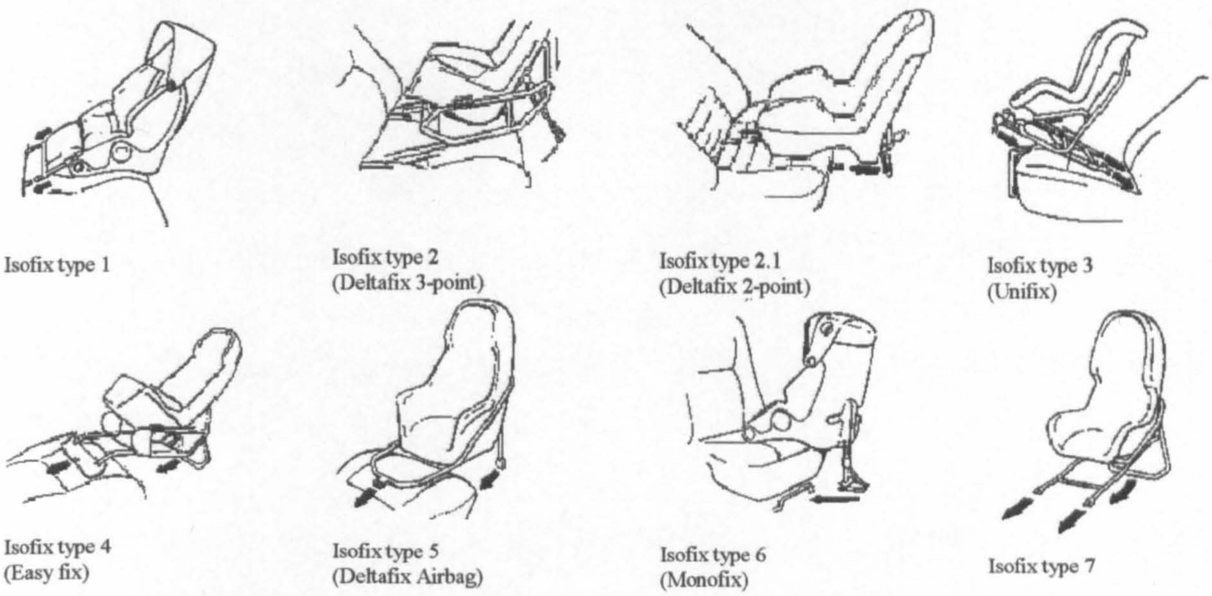


Figure 11.1 Initially proposed Isofix seating concepts

The Isofix type 3 shows the United Kingdom contribution called Unifix [11.2]. It comprised two rigid rear anchorages in the seat bight and a single rigid front anchor (that folded into position). The fixings were Ø6 mm x 25 mm long horizontal steel bars mounted to the seat frame/floor at suitable points. A modified version of this was the basis of an ISO draft standard (ISO/WD 13216-1) until early 1996. Figure 11.2 shows a prototype CRS based upon that draft standard.

Figure 11.2 Isofix (Unifix) type CRS at beginning 1996

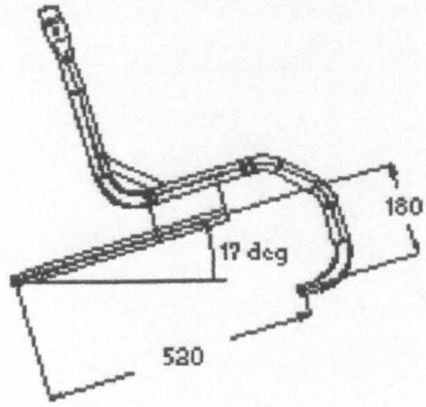


Figure 11.3 Isofix (Unifix) 4 point CRS dimensions

[The four point Isofix CRS is based on nominal chassis dimensions as indicated opposite (increased from 160 mm x 500 mm). The nominal chassis base incline to the horizontal of 17° +/- 5°.]

This concept allowed individual design initiatives during construction and/or adjustments to fit the range of seat sizes.

The lateral spacing of the latch/mounting pin centre line was specified at 280 mm, both front and rear. This allows for the possible installation of three Isofix CRS in the rear of larger vehicles, two in smaller vehicles or a single Isofix CRS in the centre seat position. Figure 11.4 shows possible rear seat attachment positions for CRS.

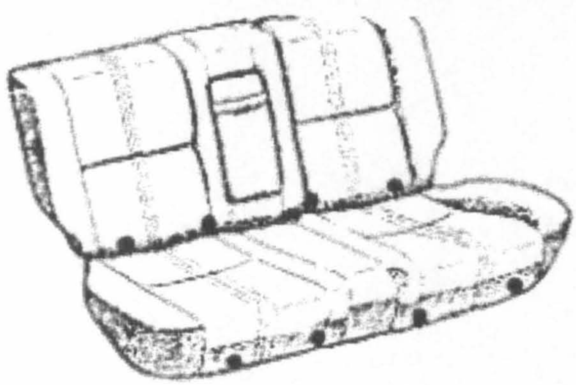


Figure 11.4 Rear seat attachment locations [11.2]

Initial calculations [11.2] and further work [11.3][10.1] confirmed the acceptability of the anchorage bars.

North America and Australasia, but not European countries, have already adopted top tether anchorage's as a requirement in vehicles to enable installation of suitably equipped conventional CRS. These attachment points allow CRS designs to incorporate top tethers securing the top of the CRS to the top of the seat back. The availability of this feature encouraged some countries proposed an alternative Isofix concept. The Canadian proposal (Canfix) was a three point anchorage system that was subsequently re-titled Causfix to reflect Australian involvement. This consists of two rigid lower anchors (similar in position and dimensions to the two rear 'four point Isofix' fixings) plus a top tether that conforms to existing belt retained CRS top tether requirements to limit rotation. Early Canfix systems as applied to North American CRS types, together with their dynamic performance is described in greater detail in [10.1].

A further alternative system favoured by the some large US auto makers is a system entitled Ucrafix, this comprised three soft tethers, two in the lower seat bight with small buckle ends and a top tether with the standard tether hook. This system has the advantage of rapid introduction in most current vehicles by attaching to existing seat belt anchorages.

In 1996/97 Causfix came to be favoured by many of the European countries due to its lack of the front anchor pins which caused package problems. However, some countries proposed Deutschfix, a version of Causfix that utilised the two rigid lower anchors without the top tether but with a ratchet system to tension the CRS into the seat cushion/back and, thus, offset the lack of top tether.

The schematics below show the four Isofix concepts evaluated as part of the UK contribution to the Isofix development programme.

(scheme A)

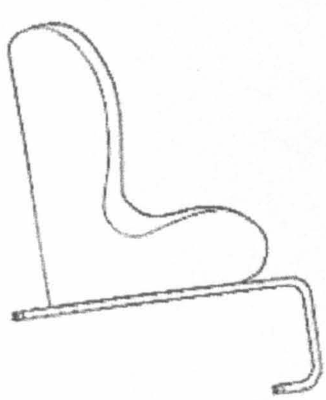


Fig 11.5 4 point Isofix

(scheme B)

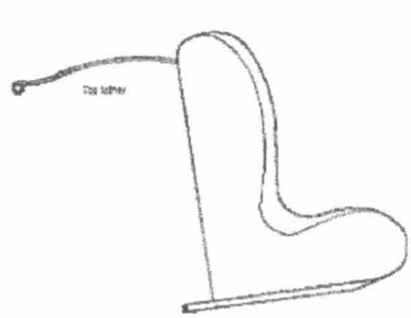


Fig 11.6 2 point + top tether Causfix

(scheme B')

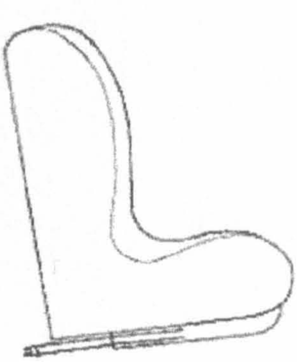


Fig 11.7 2 point + ratchet Deutschfix

(scheme C)

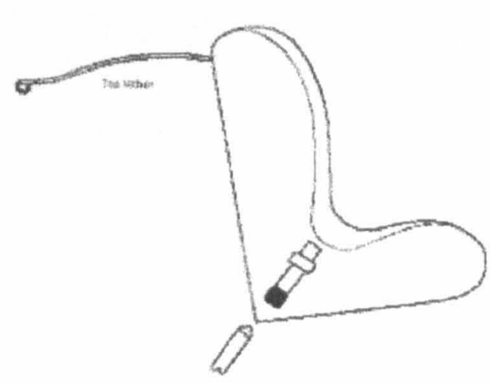


Fig 11.8 3 point (straps) Ucrafix

The four proposed concepts were assessed in forward and rear facing modes for dynamic performance and associated usability trials [11.4].

11.2. User Trials of Proposed Isofix Child Restraints

It is generally acknowledged that CRS provide invaluable protection for restrained children in survivable accidents Cuny et al [11.5], Roy [3.7]. However a continuing concern with current CRS is the problem of misuse.

To provide optimal performance restraint systems must secure the occupant as tightly as possible to the vehicle whilst allowing the wearer to ride down within the dimension of the vehicle crumple zones. Incorrect/loose installation of the CRS in the vehicle or inadequate harness fitment/adjustment can seriously affect dynamic performance. Rattenbury & Gloyns [3.6] in their study of UK car accidents in which restrained children were killed cited poor installation as a major cause for concern.

A number of deficiencies exist with the current generation of belt attached CRS and their compatibility with vehicle structure. The design deficiencies include:

1. The complexity of the adult belt routing through the CRS with the possibility for miss installation resulting in unstable/poor CRS retention, and

2. Modern adult restraint systems incorporating retractor seat belts that, even when used correctly, provide significantly inferior CRS retention to the vehicle structure compared with dedicated straps or rigid anchors. This poor retention is potentially compounded in some smaller vehicles because some CRS designs may fall off the front edge of small rear seat cushions [11.6].

The Isofix concept of dedicated CRS attachments has been developed to address both these concerns. User trials have been conducted in the UK [11.4] and North America [11.7] to assess the usability of the final Isofix concepts under consideration.

Isofix concepts :-

Scheme A : Four (rigid) point Isofix
Scheme B : Causfix, two (rigid) lower attachments, plus top tether
Scheme B' : Deutschfix, two (rigid) lower attachments, plus ratchet tensioning to seat

Scheme C : Ucrafix, three (straps) point

(these concepts are described in detail in section 11.1).

UK User Trial of CRS to Vehicle Interface [11.4]

The UK trials assessed how a sample of parents of young children were able to attach and adjust representative CRS types to a suitably equipped vehicle. The level of misuse was noted and any resulting slack in the CRS to the vehicle attachment was recorded.

The CRS assessed were all UK Group 1 forward facing seats based upon the same conventional production device.

The sample sizes in this trial were small. For conventional systems A and B the size of the sample was 29, for system C 17 , and for system C without top tether 12, subsequently identified as C'. System B' was not assessed due to time constraints.

The parents were given pictogram type fitting instructions and requested to install the seats in a small suitably equipped four door vehicle. They were required to install, remove and reinstall each seat so that re-tightening upon re-fitting could be assessed.

The following table shows the results categorised as 'well fitted', 'minor errors' or 'not fitted correctly'.

The terms are defined as follows:-

Minor errors :	Failure to settle the CRS into the vehicle seat before tightening the restraint system, or not adequately tightening belt/straps or tether.
Not fitted correctly:	Failure to deploy the webbing lock off, failure to adjust correctly or failure to use the top tether, or incorrect adult belt routing.

CRS attach Type	Adult belt	Rigid attachments		Straps	
	Convent'l belt retained	Scheme A (4 point)	Scheme B (2 point+tt)	Scheme C (2 strap+tt)	Scheme C' (2 strap)
Well fitted	13 (45%)	29 (100%)	22 (76%)	10 (59%)	6 (50%)
Minor errors	8 (27.5%)	0	6 (21%)	7 (41%)	6 (50%)
Not fitted correctly	8 (27.5%)	0	1 (3%)	0	0

Figure 11.9 UK user trial results

The trial, sample size N14, also assessed the amount of slack in the installed system. The following table indicates the measured slack in the CRS to vehicle attachment when a force of approximately 50 N is exerted on the CRS harness. Schemes A and C' were not assessed.

CRS type	Conventional belt retained		Scheme B (2 point+tt)		Scheme C (2 strap+tt)	
	≤ 25 mm slack	≤ zero slack	≤ 25 mm slack	≤ zero slack	≤ 25 mm slack	≤ zero slack
Top tether	N/A	N/A	14 (100%)	13 (93%)	13 (93%)	11 (79%)
Top of child seat shell	9 (64%)	7 (50%)	14 (100%)	14 (100%)	8 (57%)	3 (21%)
Bottom of child seat shell	7 (50%)	2 (14%)	N/A	N/A	10 (71%)	3 (21%)

Figure 11.10 UK user trial (slack remaining in system)

Additionally, a conventional CRS was attached in the centre rear seating position and parents asked to fit a second CRS on one side. The latch-in type devices (schemes A and B) presented the least problems.

North American (Canadian) User Trial of CRS to Vehicle Interface [11.7]

The British Columbia trials involved a slightly larger sample of 76 parent participants of whom 89% had previously fitted CRS in vehicles. As in the UK study the participants were

issued with pictogram type fitting instructions and, in this trial, installed the seats in a mid sized 4 door vehicle.
The CRS types under evaluation were similar to those employed in the UK study with the addition of a type C (Ucrafix) device with hooked lower straps enabling attachment to the Isofix 6 mm pin fixings and designated Type D. The prototypes were based on a conventional Australian CRS which was used for comparative baseline purposes. No B' or C' systems were included in this trial.

The Canadian results were presented in a different format to the UK results, although some comparisons are possible.

The table below details the accuracy of installation, defined as accurately attached CRS with correct routing , but with no reference to tightness of installation. The correct installation specifies strap tensioning that permits about 25 mm forward movement of both upper and lower parts of the CRS. Because scheme A, the 4 point Isofix, allows for no adjustment, this type was not included in this trial.

CRS attach Type	Adult belt	Rigid attachments		Straps	
	Convent'l belt retained	Scheme A (4 point)	Scheme B (2 point+tt)	Scheme C (2 strap+tt)	Scheme D (2 strap / hook+tt)
Accurately installed	63 (83%)	73 (96%)	76 (100%)	76 (100%)	76 (100%)
Proper installation	4 (5%)	N/A	71 (93%)	39 (51%)	18 (24%)

Figure 11.11 North American user trial installation results

Since the tightness of installation is so significant to a successful CRS installation, it is important to review the level of slack remaining in the various systems. This Canadian study records the proportion of each correctly installed CRS system type with remaining slack both top and bottom of <26 mm, <51 mm and <76 mm.

Again the 4 point system is not represented.

CRS attach Type	Adult belt	Rigid attachments		Straps	
	Convent'l belt retained	Scheme A (4 point)	Scheme B (2 point+tt)	Scheme C (2 strap+tt)	Scheme D (2 strap / hook+tt)
<26 mm slack	4 (5%)	N/A	71 (93%)	39 (51%)	18 (24%)
<51 mm slack	6 (8%)	N/A	76 (100%)	70 (92%)	48 (63%)
<76 mm slack	23 (30%)	N/A	76 (100%)	72 (95%)	72 (95%)

Figure 11.12 North American user trial, post installation slack

This trial also measured the time taken to install a CRS as this may influence consumer acceptance of these products. The results are summarised below.

Time to install (sec)	Convent'l belt retained CRS	Scheme A (4 point) Isofix	Scheme B (2 point+tt) Causfix	Scheme C (2 strap+tt) Ucrafix	Scheme D (2 strap / hook+tt)
Average time	140	46	50	92	94
Minimum	39	20	20	35	40
Maximum	362	181	240	347	282

Figure 11.13 North American user trial, time taken to install CRS

This study also considered product cost and participants indicated a reluctance to purchase any system if it cost more than approximately 50% above the recommended retail price of current belt retained systems.

Summary of User Trial Results in the UK and North America

The two studies were not reported on the same basis, making direct comparison impossible. However the results suggest the following general trends.

Conventional Adult Belt Retained CRS

The current generation of adult belt retained CRS was wrongly installed by the majority of participants in both appraisals. The difficulties experienced ranged from incorrect adult belt routing to slackness in the adult belt. The miss-installation of, say, framed (adult belt retained) forward facing CRS is a recognised problem, and the level of misuse reported in these studies does not conflict with other studies. A recent study in the USA by Eby and Kostyniuk [3.12] indicated an overall CRS misuse rate of 89%. In the UK Dorne [3.14] 1992, reported an overall misuse rate of 93% for Group 1 forward facing framed CRS (pre-ECE R44 03). In this study, 46% of the reported miss-installations were associated with adult belt routing and excessive slack. Hummel et al [3.15] 1997, indicated a misuse rate of 63% in Germany and described 33% 'severe'. The most recent study in the UK (chapter 4) indicated an overall misuse rate in excess of 80% for conventional restraints.

Isofix type CRS

Both the UK and Canadian trials indicated that the rigid anchor Isofix 4 point and Causfix produced the highest proportions of correct installation, i.e. installed on proper attachments and correctly adjusted (in case of Causfix).

Similar results were reported by Hummel et al [3.15]1997, indicating the 4 point Isofix miss-installation rate was 4%, compared with a miss-installation rate for conventional CRS of 60% - 80%. The Ucrafix (2 strap + top tether) system may appear correctly attached without the correct pre-tensioning to the vehicle seat. In the UK appraisal, the adjustment levels of Ucrafix straps was similar to the conventional CRS attached adult belt. In the Canadian appraisal, the Ucrafix system appeared to be adjusted better and more quickly than the comparable conventional adult belt retained CRS. However tensioning of the conventional system adult belt was particularly poor in the Canadian study.

Discussion of Isofix trial results

It is clear that simplified CRS attachment with minimum slack has advantages in terms of accuracy of adult belt routing and in lower loading due to improved coupling to the vehicle shell.

However, whether the benefit of the improved anchors will be seen to such a large extent in the UK as in North America is not clear. In the UK conventional CRS installation, although poor in overall terms, does emerge as slightly superior to that observed in North America where conventional CRS appear so poorly employed at present.

11.3. Crash Test Evaluation of Isofix Child Restraints (carried out by author)

The dynamic test programme conducted during 1996/7 evaluated the performance of child restraints conforming to Isofix schemes. The schemes evaluated were possible Isofix proposals similar to those assessed in the 'user trials' except that the complex latches were simplified by the substitution of representatively located holes and bolts for reliability and cost reasons. The Isofix CRS were based upon the same production base shell and associated harness systems to enable comparisons. A standard adult belt retained item was included in the evaluations as a baseline.

The following sections report the dynamic evaluations of the proposed concepts in frontal, side and rear impacts where appropriate, and include both rear and forward facing systems from Groups 0 and 1 respectively.

The tests were conducted according to the existing ECE R44 03 procedure for set-up, impact and data processing using an appropriate manikin from the TNO P range. Further evaluations were conducted using set-up conditions of excess slack in the CRS to vehicle interface similar to those in the user trials. This work has been published elsewhere [11.4] 1997, although in a different format.

The constraints of time and cost limited the programme, in most cases, to only one evaluation of each set-up configuration. Confidence in the test set-up and its repeatability have been established through extensive experience of the test facility. The deceleration pulse and sled stopping distance can be controlled to typically within ±2 g and 40 mm, manikin excursion can be measured to within 1 screen pixel, equating (in these tests) to ±3.5 mm, and accelerometer response is to ±1.5 g. Nevertheless, caution should be exercised in making inferences and when drawing conclusions based on small differences in performance between systems. The range of tests, however, added confidence to inference based on trends.

11.3.1. Forward Facing (Group 1)

The schemes evaluated were as detailed in section 11.1, (scheme A) 4 point Isofix, (scheme B) 2 point + top tether (tt) Causfix [50 N tt], (scheme B') 2 point Deutschfix [800 N pre compression] and (scheme C) 2 strap + top tether [50 N per strap and tt] Ucrafix, in addition to a conventional adult belt retained production CRS [50 N L & D].

Scheme A

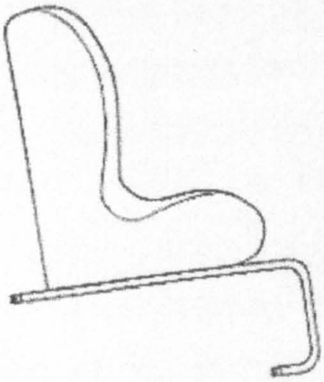


Fig 11.14 4 point Isofix

Scheme B

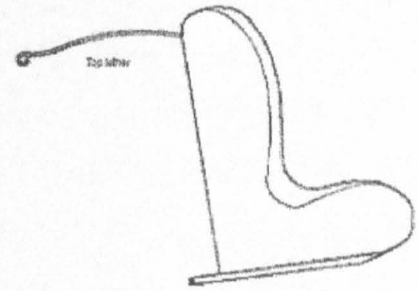


Fig 11.16 2 point + top tether Causfix

Scheme B'

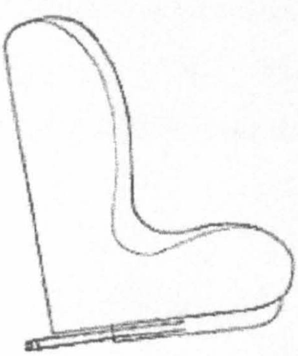


Fig 11.15 2 point + ratchet Deutschfix

Scheme C

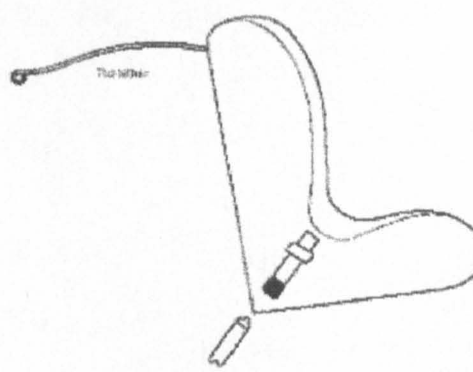


Fig 11.17 3 point (straps) Ucrafix

These data are presented in the conventional format of head excursion beyond the vehicle seat CR point, chest resultant acceleration and chest 'z' acceleration (from chest towards head, i.e. spine compressed). Where appropriate, head deceleration and neck load data are presented for comparative purposes. All acceleration data are presented in a 3 ms attenuated form.

11.3.1.1. Frontal Impact to ECE R44 03 (impact velocity 49 km/h, sled pulse 20-28 g)

The initial series of dynamic evaluations using a P3 manikin were to compare Isofix systems and to contrast results with the conventional adult belt retained CRS, all being installed optimally. The belt & strap systems are fixed to the ECE R44 03 anchorage positions chosen to be typical of European vehicles.

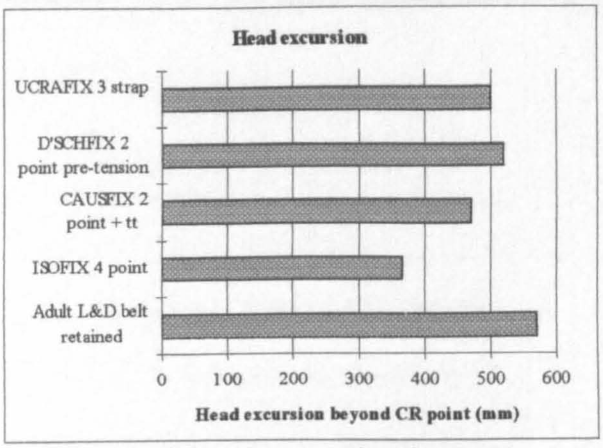


Figure 11.18 head excursion beyond CR (ECE R44 limit 550 mm)

Figure 11.18 details the improvement in occupant head excursion possible with the various systems. The smallest excursion value is linked with the most rigid attachment concept, the four point device. Both rigid lower anchor two point devices were acceptable, the device incorporating the top tether being the preferable, whilst the dedicated soft anchor device employing the typical European anchor positions was comparable. In these tests the adult belt anchored device was very close to the current 550 mm excursion standard. The anchor position used to retain the Ucrafix system affected its performance similar to the effect of ECE R44 02 and 03 anchor positions on conventional CRS. Figures 11.19 and 11.20 show the improvement in Ucrafix performance when installed on the more 'rearward' North American FMVSS 213, compared to the 'forward' ECE R44 03 anchors.

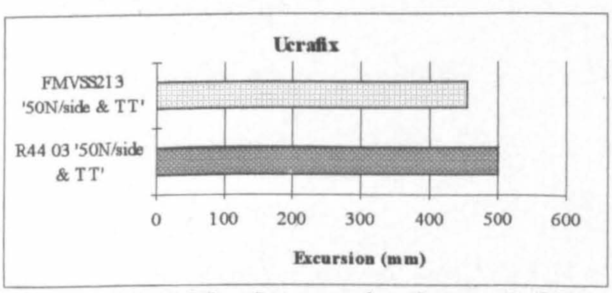


Figure 11.19 Head excursion beyond CR ECE R44 vs. FMVSS 213 anchors

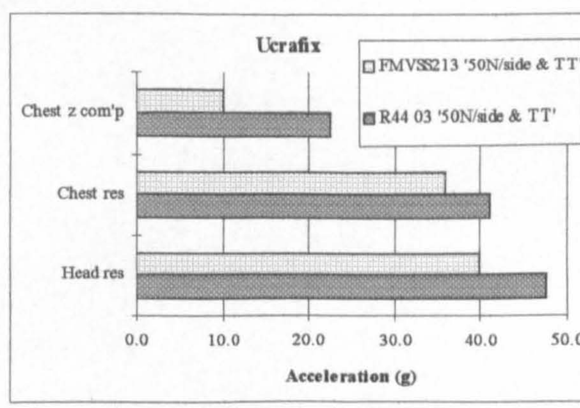


Figure 11.20 Accelerations, ECE R44 vs. FMVSS 213 anchors

A review of occupant acceleration levels (Figure 11.21) in the various Isofix systems (using ECE R44 03 anchors where appropriate) indicate lower peak chest accelerations, although those systems less firmly attached have slightly greater 'z' (compressive) component. The acceleration levels of conventional CRS were satisfactory, perhaps because the co-polymer production CRS shells offer some compliance in its base, unlike the prototype Isofix devices which were based on steel frames. The overall tendency is for the rigid anchor devices to exhibit a benefit.

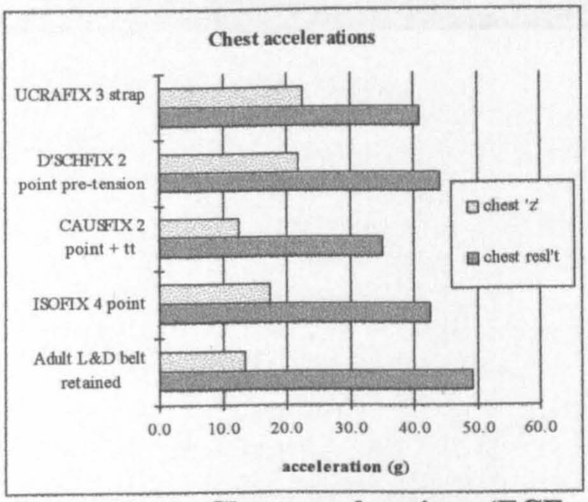


Figure 11.21 Chest accelerations (ECE R44 limit 30 g & 55 g) P3 manikin

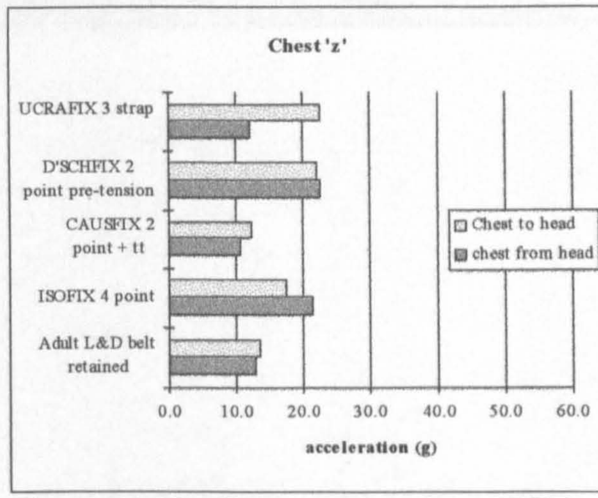


Figure 11.22 Chest accelerations (ECE R44 limit 30 g chest to head) P3 manikin

Figure 11.22 compares the peak compressive 'z' and peak tensile 'z' and shows the Deutschfix without top tether to impose slightly inferior overall spine loading characteristics compared with the other systems, although all systems exhibited acceptable performance with respect to the ECE R44 standard limit of 30 g (chest to head).

Influence of slack

In the user trials CRS were often poorly installed and all except the four point Isofix system required adjustment. Figures 11.23 to 11.25 detail the effect of CRS-vehicle interface slack on dynamic performance. The effect on head excursion, chest resultant and chest 'z' (chest to head) acceleration is shown for all the adjustable systems.

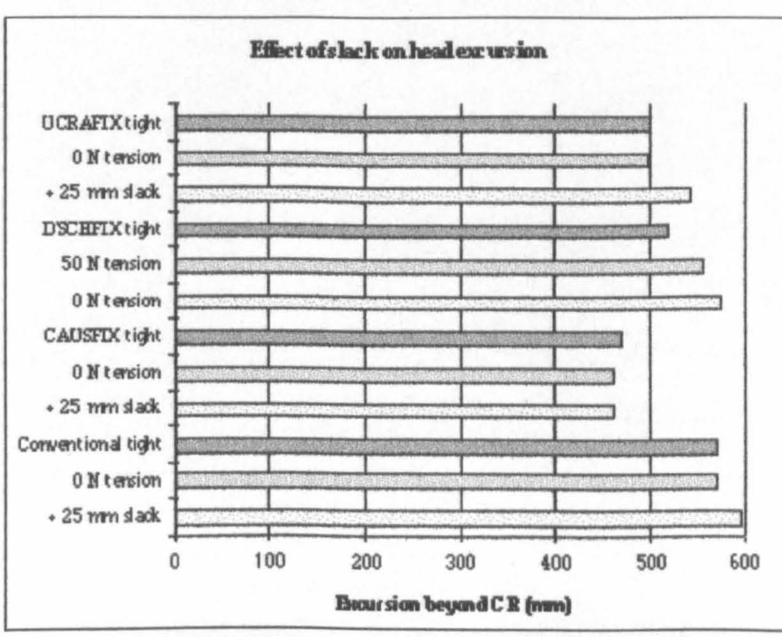


Figure 11.23 Effect of slack on head excursion

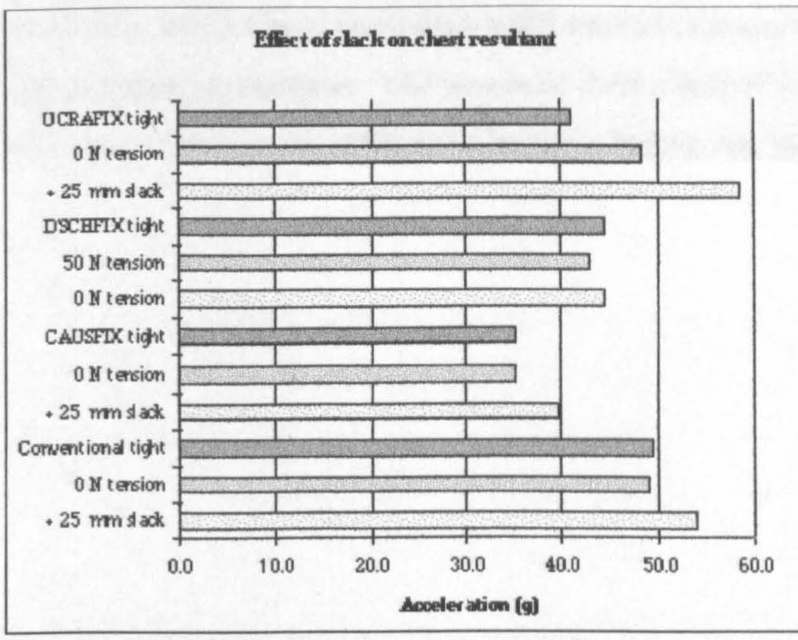


Figure 11.24 Effect of slack on chest resultant acceleration

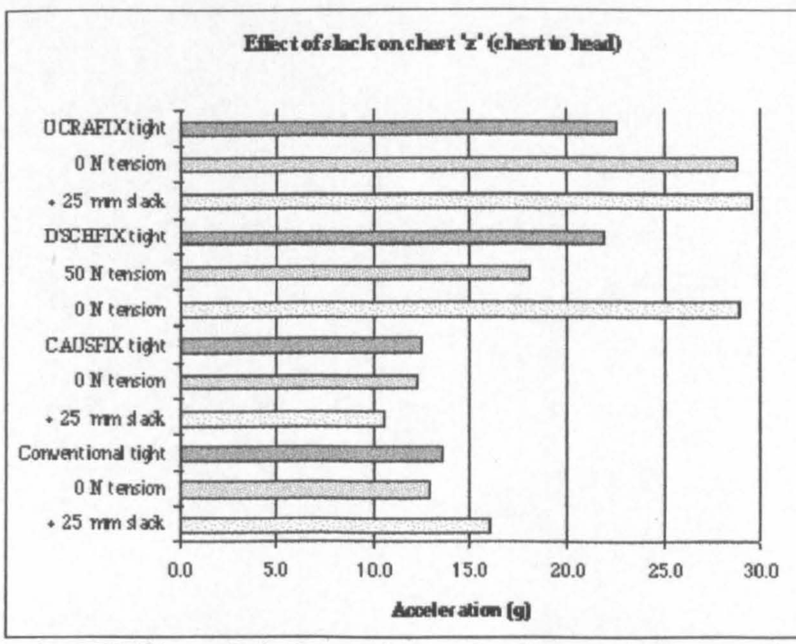


Figure 11.25 Effect of slack on chest 'z' (chest to head) acceleration

The conventional adult belt retained CRS exhibits little sensitivity to slack up to the 25 mm limit, possibly due to a combination of relatively poor retention with 50 N tension in the adult L & D belt and the 'big foot' design of the CRS tested. Considerable tension in the adult belt is specified in manufacturers' CRS installation instructions; most recommend kneeling on the CRS whilst tightening the adult belt (not always practicable). Complying with this recommendation can achieve considerably greater tension than the 50 N or 75 N set up requirement of ECE R44 03. Of the Isofix devices, Causfix with its top tether (scheme B) was least affected in terms of both head excursion and chest acceleration. The two devices which rely on the vehicle cushion for support respond less favourably to slackness in the system; the soft strap Ucrafix (scheme C) exhibited a tendency towards higher acceleration levels, whilst Deutschfix (scheme B') showed increased head excursion and chest 'z' (chest to head) acceleration. This increased chest acceleration is probably due to more aggressive contact between the CRS and seat pan when the seat cushion bottomed out.

The Ucrafix system (scheme C) was designed to operate on the more 'rearward' FMVSS 213 adult belt anchorage positions found in the larger US vehicles so the Ucrafix tests were repeated using FMVSS 213 anchor positions.

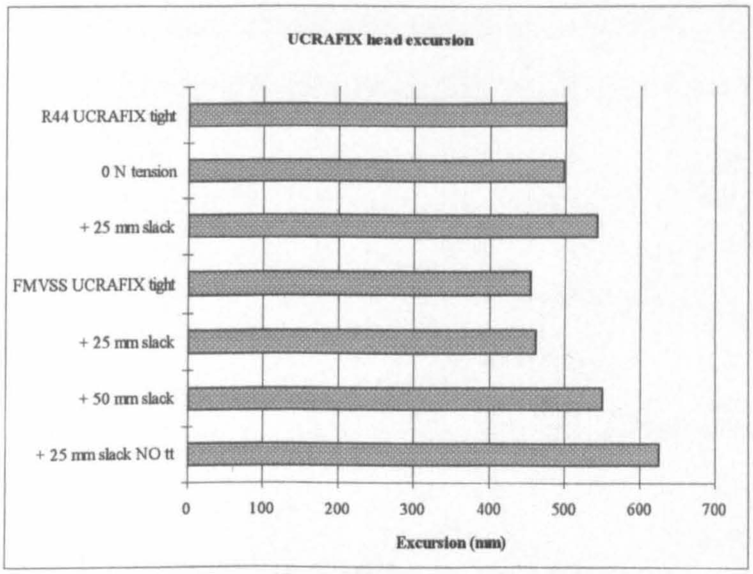


Figure 11.26 The effect of slack on Ucrafix head excursion ECE R44 vs FMVSS 213 anchor positions

Figures 11.26 and 11.27 show how increased slack progressively undermines performance with the 'rearward' FMVSS 213 anchorage positions compared with the ECE R44 03 anchors. The removal of the top tether increased head excursion, reduced chest resultant acceleration levels, but increased chest 'z' (chest to head) levels.

The decrease in resultant chest acceleration levels is attributed to greater overall ride down distance.

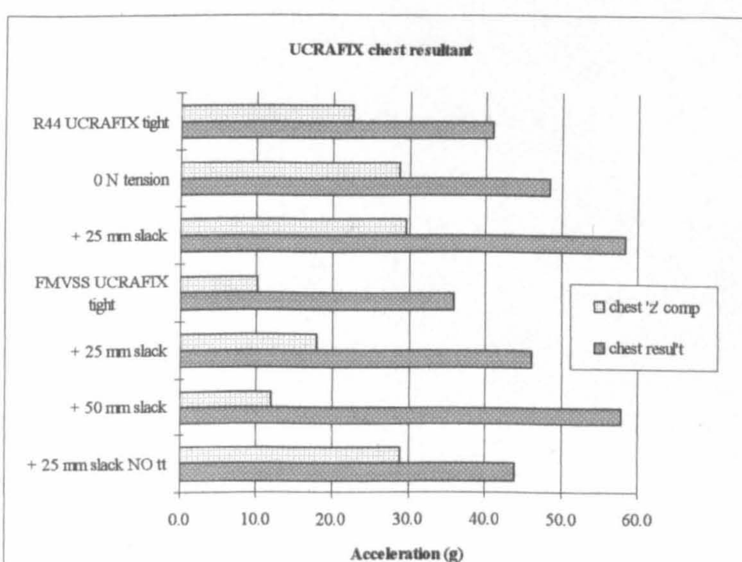


Figure 11.27 The effect of slack on Ucrafix chest acceleration ECE R44 vs FMVSS 213 anchor positions

The removal of the top tether offset the increased bottoming out effect of the seat cushion. In this configuration the ECE R44 head excursion criteria is exceeded by a considerable margin and the chest 'z' (chest to head) acceleration approaches specified acceptance levels.

The failure to use a top tether in systems that require its use is of concern in Canada and Australia where top tethers are common features on conventional CRS. Top tether usage rate of 65% have been reported in Quebec Legault F 1996 [11.8][11.9] although Australian usage rates are thought to be higher [11.9]. In the USA the use of tethers is not universal and compliance is low.

The two Isofix proposals requiring the use of top tethers are Causfix and Ucrafix (systems B and C). Figure 11.28 compares the performance of these systems with the top tether removed with a conventional CRS loosely installed. The Ucrafix system was installed on the more favourable 'rearward' FMVSS 213 anchor positions.

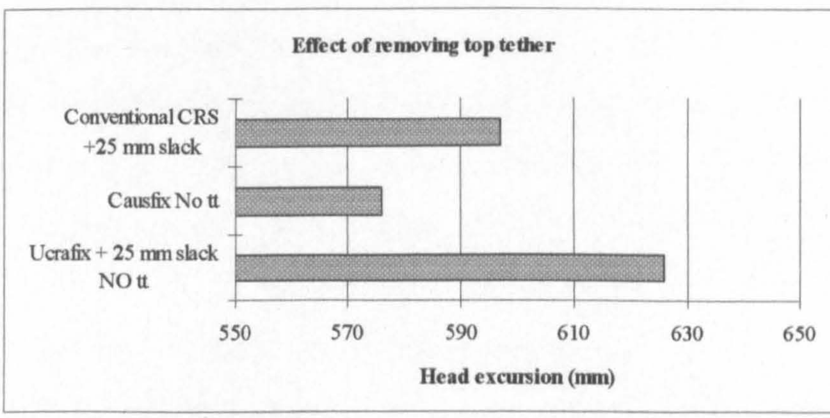


Figure 11.28 Effect of Non use of top tether on head excursion

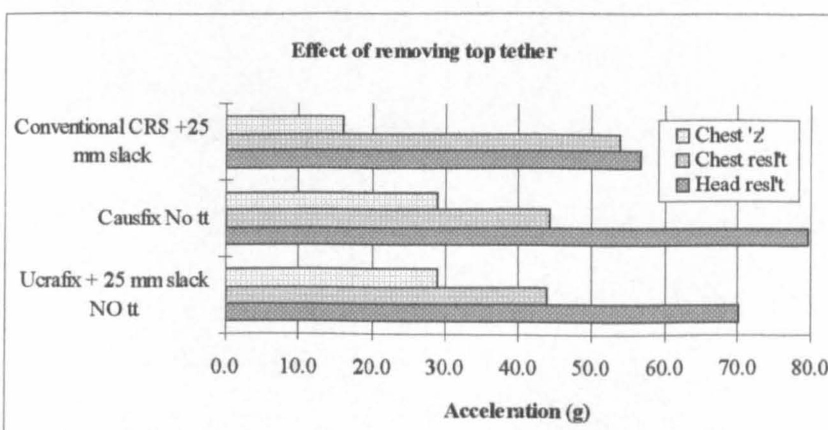


Figure 11.29 Effect of Non use of top tether on acceleration levels

The three miss-installed systems failed to meet the 550 mm maximum head excursion requirements of ECE R44 although Causfix was the least affected. All three met the requirements for chest acceleration. With respect to the two Isofix systems, the removal of the top tether appears to have greatest effect on the Ucrafix system with particular respect to head excursion and acceleration. The Causfix system appears less sensitive with respect to excursion, however the elevated head acceleration level is of concern.

Loads Induced in the Occupants Neck due to Non Contact Inertial Loading

Although not a CRS approval requirement, child occupants' neck loading during a deceleration is an area of concern. The ECE R44 specifies a 30 g limit on chest 'z' acceleration (chest toward head) measured along the torso which effectively limits spine (neck) compressive forces.

Since the Isofix concept improves the coupling between occupant and vehicle, which reduces chest deceleration levels, it follows that horizontal neck loading should be similarly reduced. However in the vertical plane there is no mechanism to absorb the energy.

A series of tests on the proposed Isofix concepts and conventional adult belt retained CRS were conducted to explore the comparative loading on a child's cervical spine during frontal impact. Figure 11.30 shows the induced (Fz) tensile/compressive and (Fx) shear loads on the upper neck joint and the derived bending moment (Mb) in flexion and in extension about the atlas axis joint, all on the midsagittal plane. The heavier TNO P3 manikin used for these tests therefore offered 'worst case' conditions for Group 1 CRS.

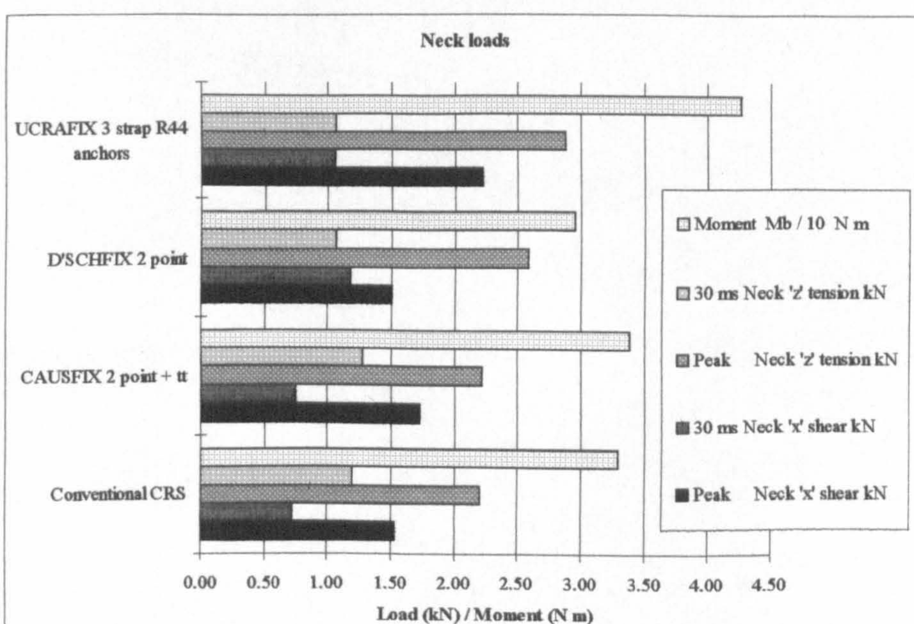


Figure 11.30 Neck loading induced (std set up) P3 manikin

The comparative results indicate an increase in peak tensile neck loading with both the Deutschfix and Ucrafix concepts, but the 30 ms attenuated value remain commensurate with the conventional CRS value. The proximity of the peak to the 30 ms shear value for the Deutschfix indicates a flatter response. These 30 ms shear values are higher than those for conventional and Causfix devices and the Ucrafix CRS. Compared with the conventional CRS, the peak bending moments in flexion for the Ucrafix and Causfix are greater but slightly lower for the Deutschfix.

These comparative tests were with the heaviest of the P3 manikin range specified for Group 1 forward facing CRS and high induced neck loads were predictable. Since heavier manikins represent older children then tolerance limits may be a function of age. To assess whether a younger occupant may also be at risk of high neck loads these tests were repeated using two basic Isofix devices with rigid and soft (R44 03) lower anchors and a P3/4 manikin. The induced neck loading is summarised in figure 11.31 along side figures 11.32 and 11.33 showing the ECE R44 acceptance criteria. The three CRS were all installed with the recommended adult belt tension.

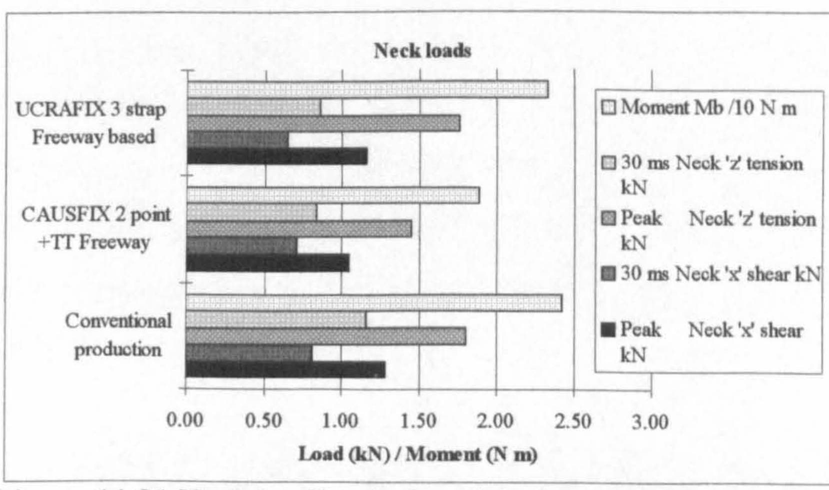


Figure 11.31 Neck loading induced (std set up) P3/4 manikin

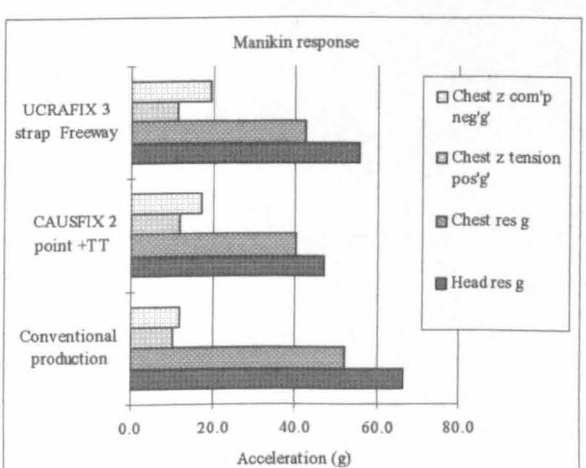


Figure 11.32 Manikin accelerations (std set up) P3/4 manikin

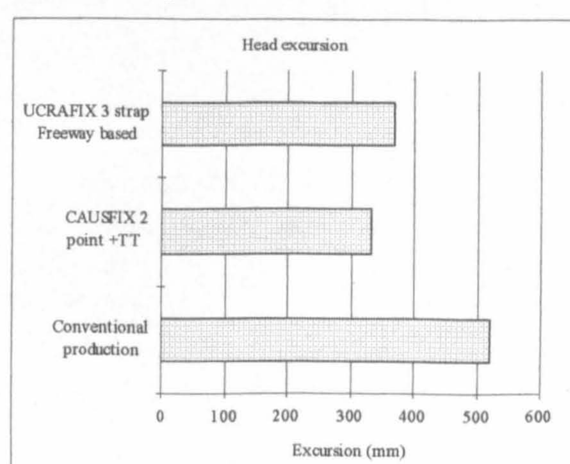


Figure 11.33 Head excursion (std set up) P3/4 manikin

Neck loading peak values are lower for the smaller/lighter manikin, although the 30 ms values are not proportionally lower for the conventional system. For the Causfix only, there was a reduction in the 30 ms tensile value.

For all systems, head excursion values were lower with the lighter manikin especially in the more securely restrained Isofix systems. These recorded lower excursion values of between 130 and 140 mm with respect to the P3, with the conventional system recording a value approximately 50 mm lower.

Chest resultant data are influenced by lower manikin mass and relatively stiff webbing. The more securely retained Causfix exhibited a slightly increased chest resultant value, the Ucrafix system was similar to the P3 value, whilst the conventional system demonstrated a slight increase for this parameter. Chest 'z' compression and subsequent tension were largely unaffected.

11.3.1.2. Side Impact to New Zealand Standard, NZS 5411:1991

The less common side impact type of accident is potentially more serious in terms of injury, Langwieder et al [11.10]. The ECE R44 03 acceptance standard, although comprehensive and exacting in most respects, does not require a dynamic side impact evaluation. In reality, side impact protection is restricted to specifications detailing areas of energy absorbing material in the child's head area combined with a head form drop test to confirm its energy absorption properties.

Only New Zealand and Australia [2.2][2.3] require full scale side impact dynamic tests of the CRS and occupant attachment system to the vehicle. These tests are similar in that a child manikin is restrained on a test seat on a conventional single sled. They do not consider intruding structure.

The forward facing Isofix proposals and current CRS were evaluated to the dynamic requirements of current NZS 5411:1991 at an impact velocity of 32 km/h and a 14-20 g (nominally 16 g) sled pulse. Compliance is based on chest acceleration levels and head excursion measured from the centre line of the test bench. Although head acceleration is also reported it must be treated with caution because of the inferior biofidelic response of the manikin's neck.

A limited number of tests were conducted in the forward facing configuration with the heavier P3 manikin correctly installed in the CRS systems. Figures 11.34 and 11.35

compare head and chest acceleration and the head excursion. Since there is no reference to intruding structure in the NZ standard, excursion is the primary parameter used to assess the effectiveness of the system.

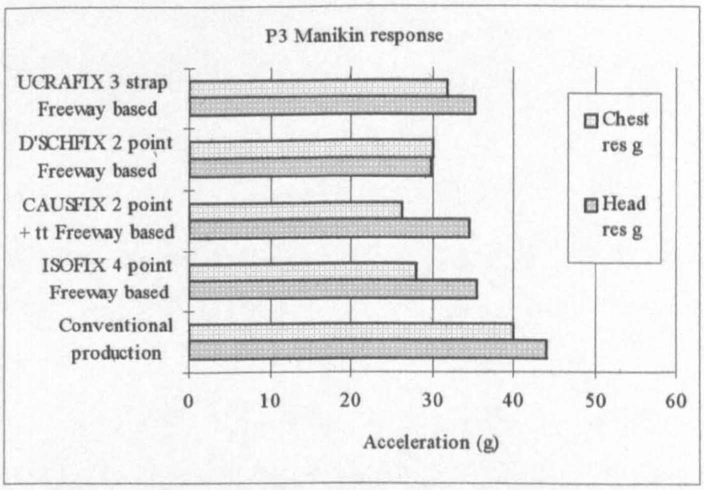


Figure 11.34 P3 manikin acceleration in New Zealand side impact test

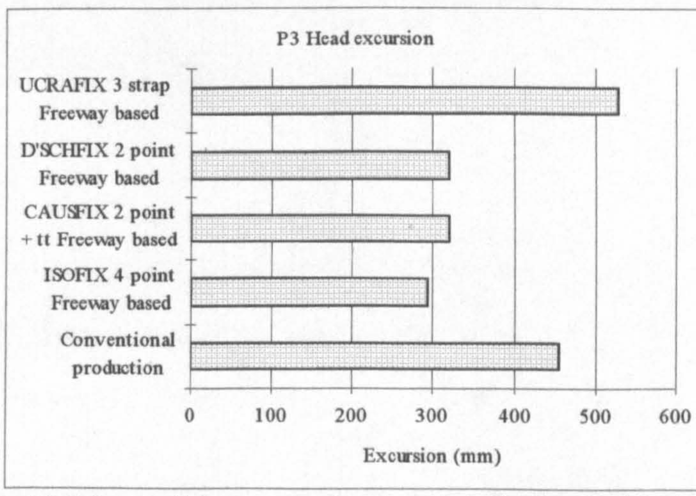


Figure 11.35 P3 manikin excursion in New Zealand side impact test

Those systems deploying soft fixings (straps/belts) to attach the CRS to the test seat are at a significant disadvantage to those systems with rigid fixings. The significantly greater excursion levels of the conventional and, particularly, the Ucrafix systems compared to the Isofix, Causfix and Deutschfix systems serve to emphasise the potential danger of contact with intruding structure. Whilst all the systems were installed optimally, with the correct specified strap tensions, the conventional system was tested in its most favourable configuration with the diagonal section of the adult belt on the impact side. All harness set-up procedures were as specified in ECE R44. The Ucrafix system was attached to the most 'forward' ECE R44 03 anchorage position possible in European vehicles. The excursion of the forward facing Ucrafix system was minimised by using the 'rearward' FMVSS 213 anchor positions. Figures 11.36 and 11.37 show the relative performance of the Ucrafix system when attached to the two lower anchor positions.

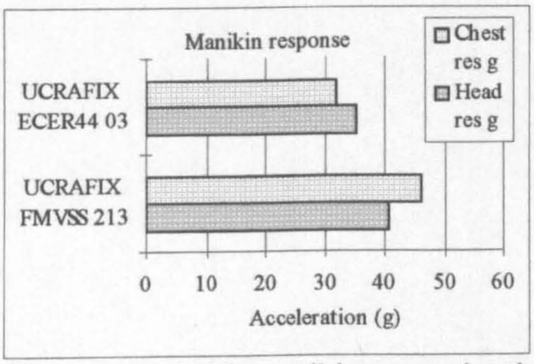


Figure 11.36 P3 manikin excursion in New Zealand side impact test

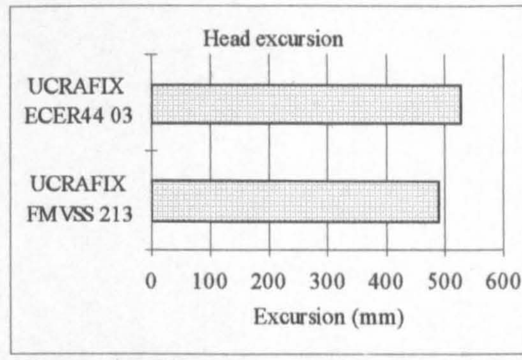


Figure 11.37 P3 manikin excursion in New Zealand side impact test

The 'rearward' lower anchor positions offer superior securing of the CRS to the test seat and, as a consequence, head excursion was reduced slightly but offset by an increase in acceleration levels. Even with the benefit of 'rearward' anchor positions the Ucrafix was the least favourable of the systems evaluated.

Influence of Slack

As in frontal impacts, the effect of slack in the CRS to vehicle interface significantly affects overall performance. Figures 11.38 and 11.39 detail the inferior performance of CRS types that are susceptible to slack if installation is faulty. In these tests the Ucrafix used FMVSS 213 anchorages.

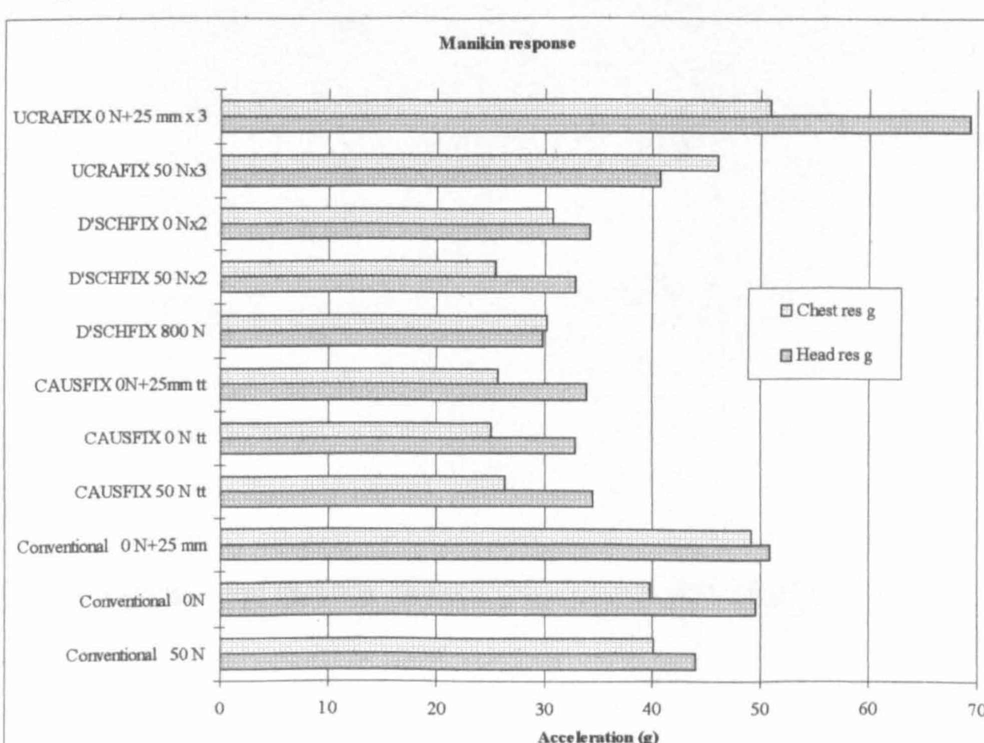


Figure 11.38 Effect of slack on acceleration levels P3 manikin in New Zealand side impact test

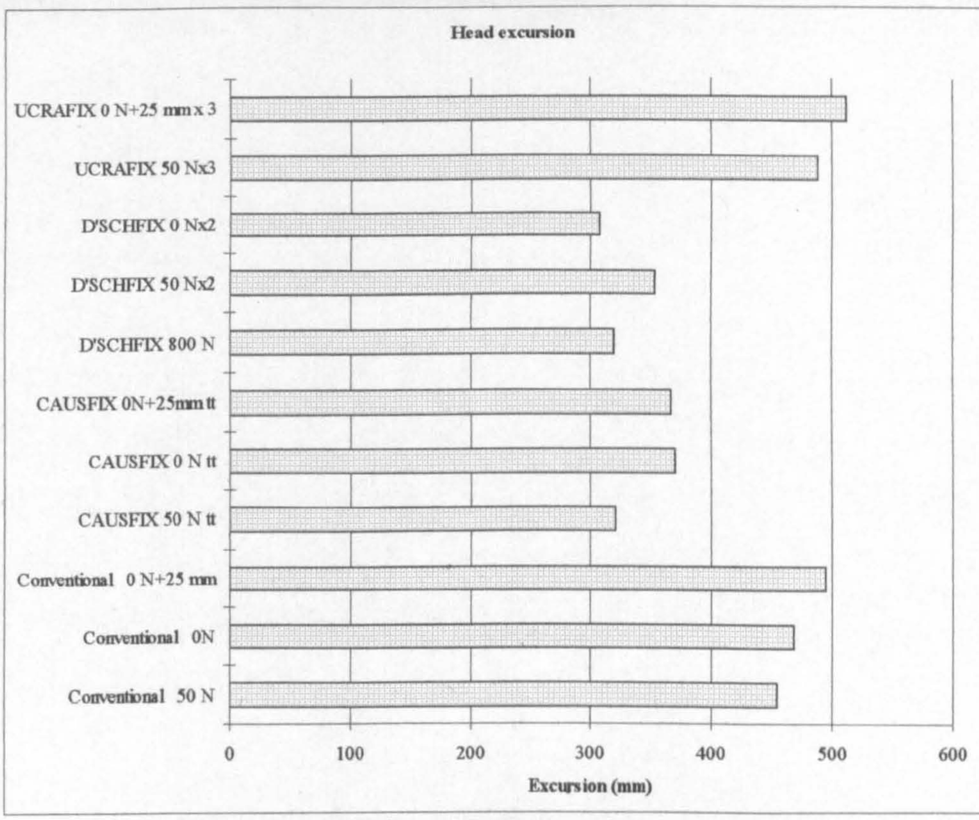


Figure 11.39 Effect of slack on head excursion P3 manikin in New Zealand side impact test

For top tether CRS types, excessive excursions occur when the tether is omitted or poorly fitted (figures 11.39 and 11.41). Again the Ucrafix is fitted on FMVSS 213 anchorages.

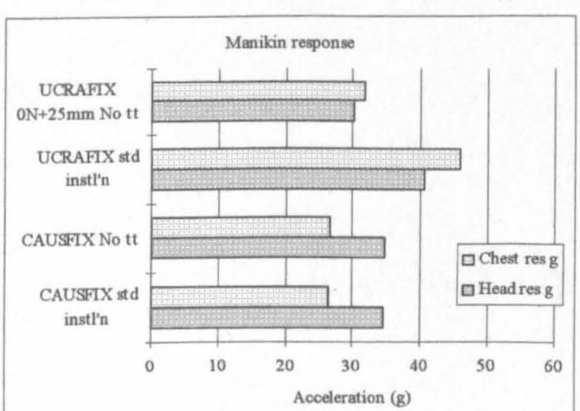


Figure 11.40 Effect of tt deletion on acceleration levels P3 manikin in New Zealand side impact test

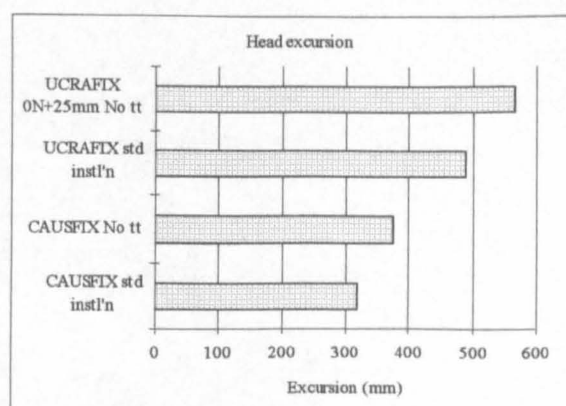


Figure 11.41 Effect of tt deletion on head excursion P3 manikin in New Zealand side impact test

These results support the use of rigid fixings over soft fixings for CRS systems. The overall performance is superior and they are less sensitive to poor installation.

11.3.1.3. Rear Impact to ECE R44 03 (31 km/h impact, 14-21 g sled pulse)

Simulated rear impact tests of forward facing Group 1 systems were conducted at 32 km/h and a 14-20 g (nominally 16 g) sled pulse (it should be noted that rear impact tests are only required on rear facing devices in ECE R44).

On impact the load is distributed over the CRS back and the energy absorbed. If the back of the seat is of sufficient height it will prevent neck extension and reduce the possibility of neck injury. Figure 11.42 describes the performance of conventional CRS and various Isofix systems. Ucrafix was excluded as its performance is similar to a conventional restraint in rear impact. In this configuration, excursion is constrained by the seat back and not recorded.

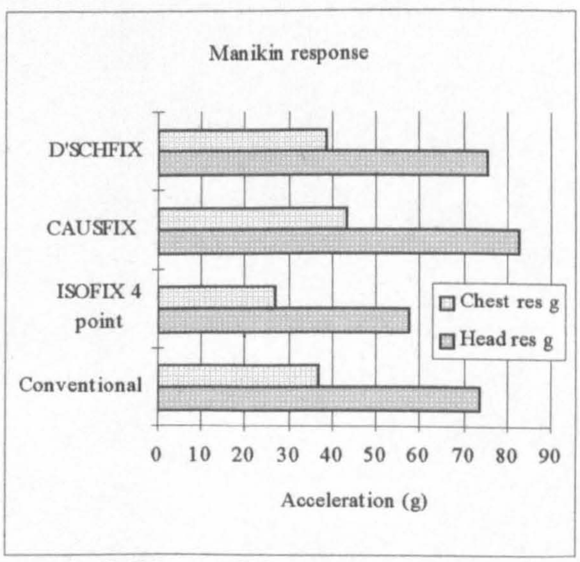


Figure 11.42 P3 manikin response in rear impact

For the very rigid four point system there was little relative movement between the CRS and sled. All the systems performed satisfactorily in terms of chest resultant but the head resultant was approximately double the chest resultant. The high chest resultant was surprising given the solid back support. The Deutschfix with cushion pre-compression performed slightly better than the similar but less firmly installed Causfix. For all devices, the acceleration traces showed the head resultant to be comprised primarily of the 'x' component implying contact with the back of the CRS shell.

11.3.2. Rear facing (groups 0 & 1) CRS

The Group 0 rear facing infant carrier schemes evaluated were

(1) a four point Isofix

(2) a two point + V shape top tether Causfix [50 N tt], and

(3) a 2 strap + V shape top tether [50 N straps and top tether] Ucrafix, and a conventional adult belt retained production CRS [50 N L & D].

In each case the P3/4 manikin was used. The 2 point Deutschfix [800 N pre compression] was not evaluated as an infant carrier due to time delays in the manufacture of the 'pram handle' section (necessary to facilitate pre-compression into the test seat).

Scheme A

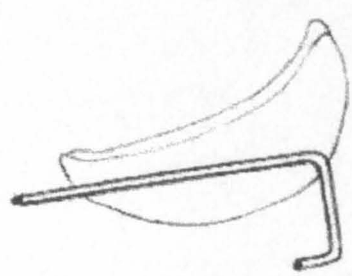


Fig 11.43 4 point Isofix

Scheme B

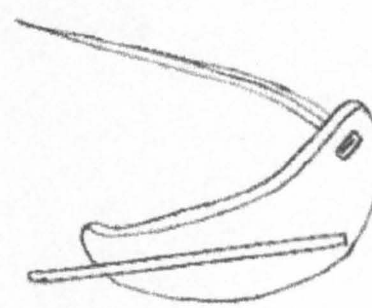
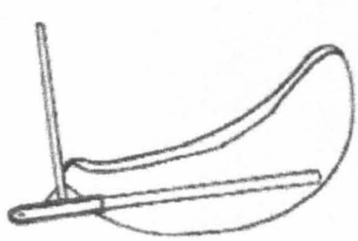


Fig 11.45 2 point + top tether Causfix

Scheme B'



NOT EVALUATED

Fig 11.44 2 point + ratchet Deutschfix

Scheme C

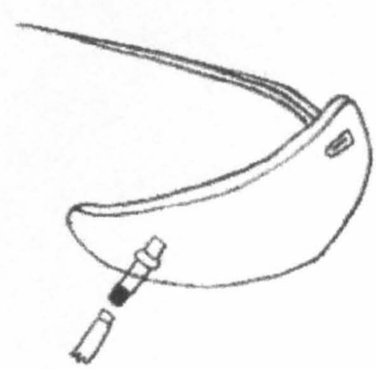


Fig 11.46 3 point (straps) Ucrafix

The Group 1 rear facing child restraint schemes evaluated with the P3 manikin were as follows: (scheme A) 4 point Isofix, (scheme B) 2 point + V shape top tether Causfix [50 N tt], (scheme B') 2 point Deutschfix [800 N pre compression] and (scheme C) 2 strap + V shape top tether Ucrafix [50 N each strap and tt].

Scheme A

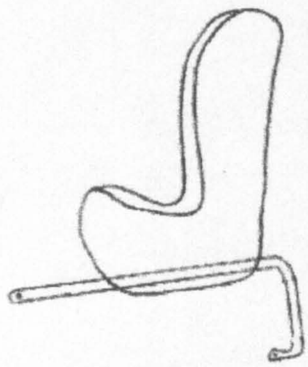


Fig 11.47 4 point Isofix

Scheme B

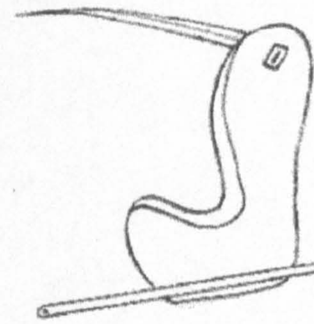


Fig 11.49 2 point + top tether Causfix

Scheme B'

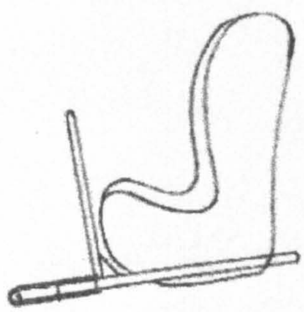


Fig 11.48 2 point + ratchet Deutschfix

Scheme C

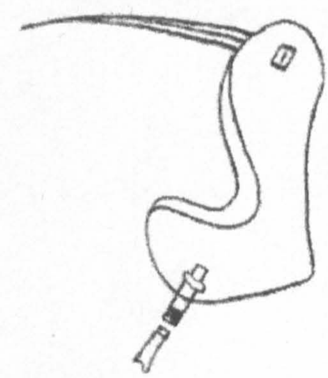


Fig 11.50 3 point (straps) Ucrafix

The set up and test procedures were similar to those for the forward facing Group 1 tests previously described. All acceleration data is presented in a 3 ms attenuated form.

11.3.2.1. Frontal Impact to ECE R44 03

Group 0 Rear Facing Infant Carrier

Rear facing Group 0 infant carriers that are not supported by the vehicle instrument panel are required by the ECE R44 standard to meet the same manikin acceleration limits as forward facing devices. For rear facing carriers, however, the head excursion limit is 600 mm beyond the CR point of the seat. Using the P3/4 manikin and standard set up conditions, all systems complied with the standard with the exception of the Ucrafix system.

The Ucrafix device on R44 anchors exceeded the chest resultant limit of 55 g. The Causfix device recorded a chest resultant limit at 52 g but the lowest acceleration levels were recorded by the most closely coupled four point Isofix.

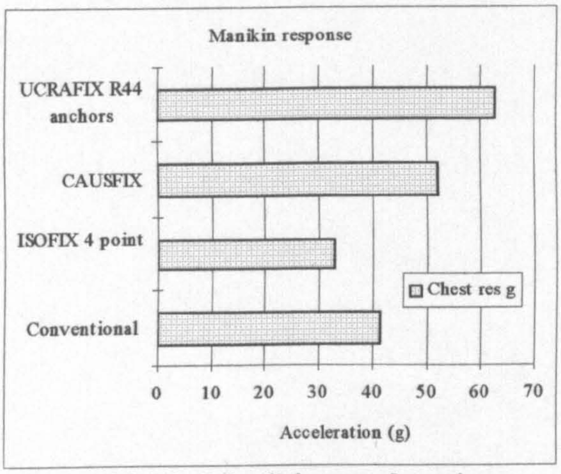


Figure 11.51 Manikin acceleration (std set up) P3/4 manikin

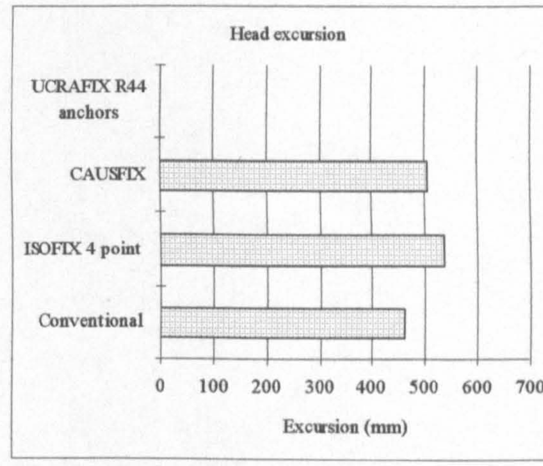


Figure 11.52 Head excursion (std set up) P3/4 manikin

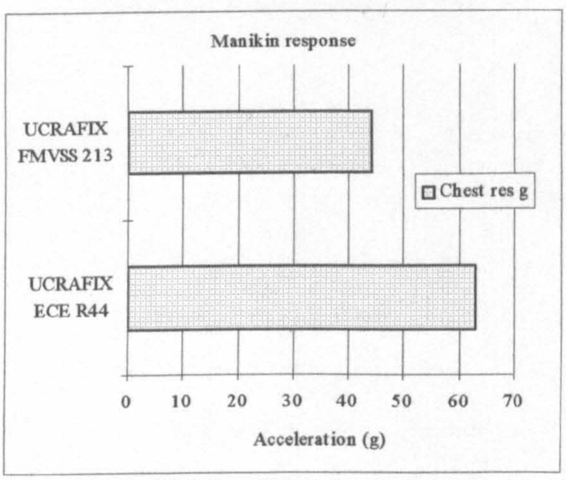


Figure 11.53 Manikin acceleration ECE R44 03 Vs FMVSS 213

The performance of the Ucrafix device when installed upon the FMVSS 213 'rearward' anchorages improved significantly as shown in figure 11.53

Group 1 Rear Facing Child Restraint

Larger rear facing CRS are common in some territories, particularly the Scandinavian countries. There it is common to transport children as old as 4 years in such devices. Because of their size and the need for leg space these CRS are located either in the front passenger seat position with its back resting against the facia or the centre rear seat of relatively large vehicles.

The rear facing CRS augmented by the Isofix attachment should be the preferred device in frontal impacts and the deceleration results of a limited number of rear facing group 1 tests of this configuration are shown in figure 11.54. At the time of testing there was no baseline conventional system as these devices are uncommon in the UK. Figure 11.55 compares the performance of forward with similar rear facing devices.

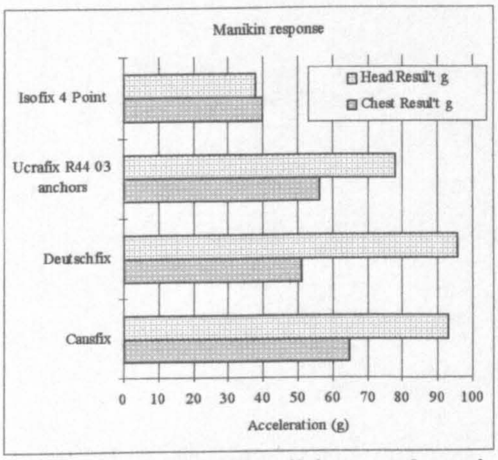


Figure 11.54 Manikin accelerations rear facing Group 1 CRS

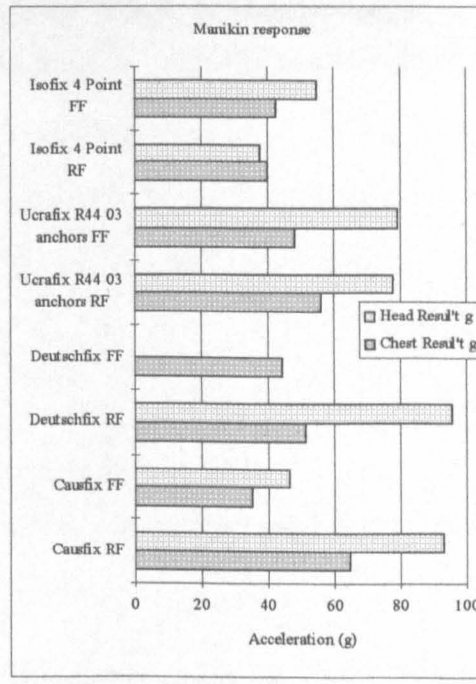


Figure 11.55 Resultant accelerations Rear Vs forward facing

Head excursion limits for large Group 0+ and Group 1 CRS that do not rest on the vehicle facia are described in the standard (paragraph 7.1.4.4.1.2.3 of ECE R44). However, the standard requires that the CRS is positioned so that contact may be made in a deceleration event. To permit direct comparison of all Isofix systems under evaluation, the tests were conducted without a facia in place. ECE R44 03 specifies a horizontal head excursion limit for rear facing devices other than group 0, not supported by the dashboard of 700 mm and a vertical limit of 800 mm above the CR point. In the large rear facing devices the occupant can ride up the back of the CRS during an impact and may exceed the 800 mm limit and strike the vehicle roof or header rail. Figure 11.56 shows the vertical excursion of the manikin head and the forward horizontal excursion of both the head and the back of the CRS seat. The difference between the forward excursion of the seat back and of the head was evidence that the head rode over the seat both vertically and horizontally exposing it to possible direct impact. All the systems evaluated except the 4 point caused concern with respect to the ECE R44 upper vertical head excursion of 800 mm or greater.

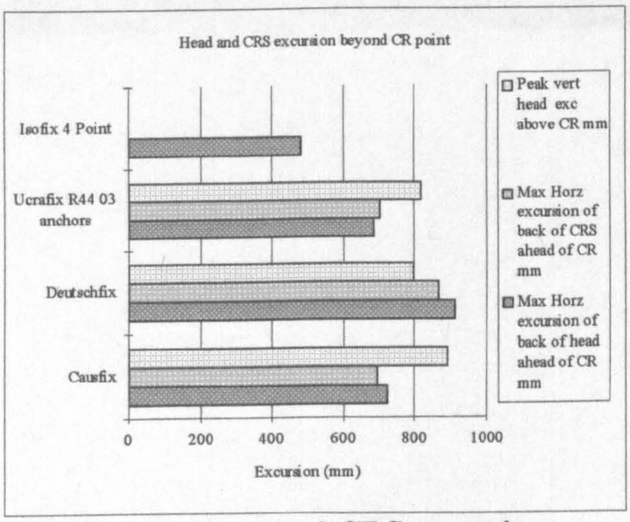


Figure 11.56 Head and CRS excursion

Only the more securely attached devices met the horizontal excursion requirement (rigid anchor or with top tether).

With such large rear facing devices the initial (back of) head position was 560 mm in front of the CR point which notably is already beyond the ECE R44 (forward facing) excursion limit of 550 mm. This in a front seat position places the head very near the front of the vehicle and more vulnerable to intrusion in a frontal impact. Figure 11.56 shows excursions of over 900 mm for the rear facing Deutschfix. This suggests that the centre rear seat position may be a more suitable location for such devices especially in a smaller vehicle.

The rear facing CRS systems compared unfavourably with front facing systems in terms of both acceleration levels and head excursion values. Closer examination of the resultant acceleration traces shows a significant vertical 'z' component as well as the expected horizontal 'x' component. On impact, the manikin rode up the back of the seat until abruptly restrained by the harness. The video also showed how the moulded shell distorted and how this contributed to the excursion values.

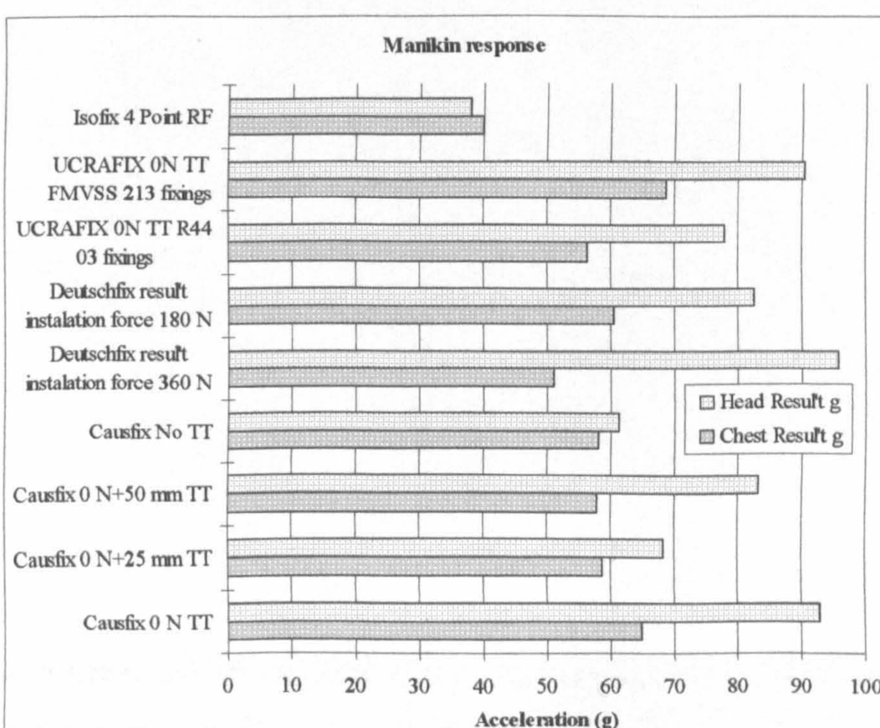


Figure 11.57 Effect of slack on manikin acceleration response

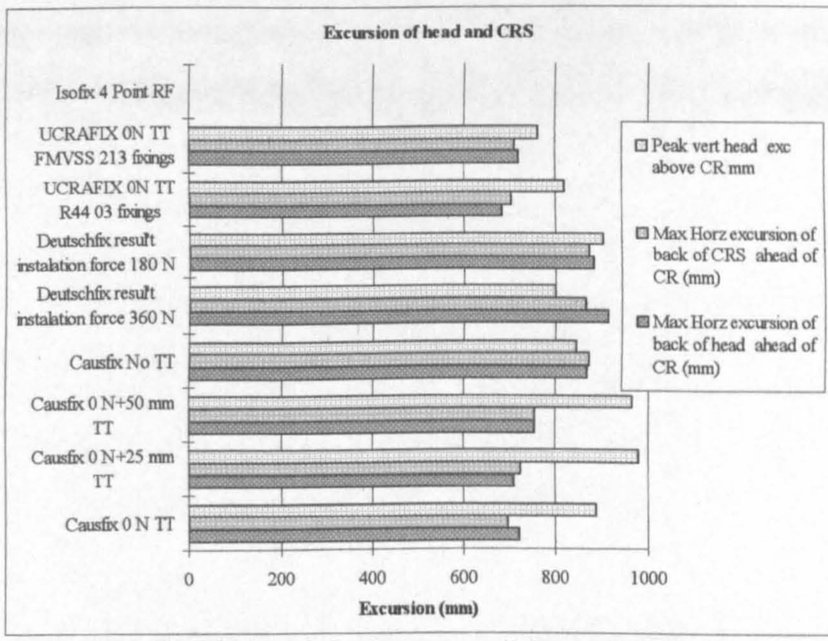


Figure 11.58 Effect of slack on manikin and CRS excursion

Figures 11.57 and 11.58 show the effect of belt slackness on these large Group 1 rear facing CRS in an R44 frontal impact. Those systems without a top tether restraint exhibited greater excursion values.

11.3.2.2. Side impact to New Zealand standard, NZS 5411:1991

The side impact test procedure has been described previously. The data following describes the response of the Group 0 infant carriers and larger Group 1 rear facing CRS.

Group 0 rear facing infant carrier

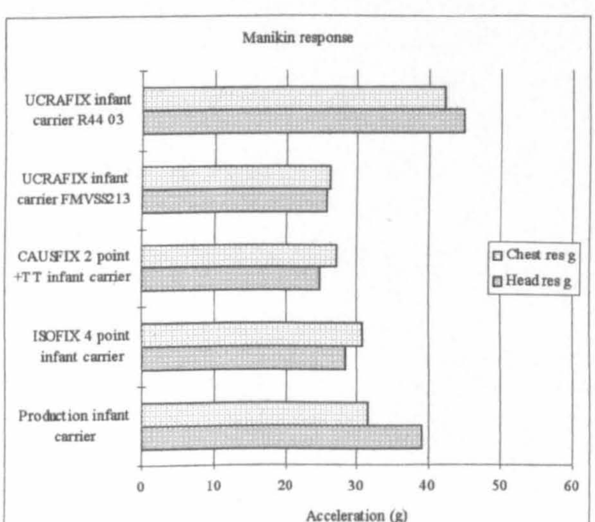


Figure 11.59 Manikin accelerations

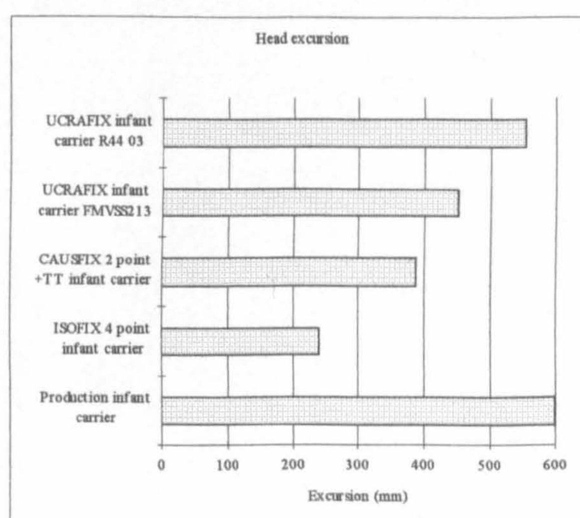


Figure 11.60 Manikin excursions from centre line of test seat.

Overall, the soft tether and belt retained devices did not perform as well in a side impact as those with rigid anchors, the only exception was the Ucrafix on the 'rearward' anchorages with its lower acceleration levels. The four point Isofix device recorded the lowest excursion. The resultant acceleration levels of all devices were within the accepted limits. Figures 11.61 and 11.62 indicate performance levels of the systems when installed to a standard less than optimal. Again the rigid anchor Isofix devices were less sensitive than the soft tether devices to poor installation, particularly with respect to excursion.

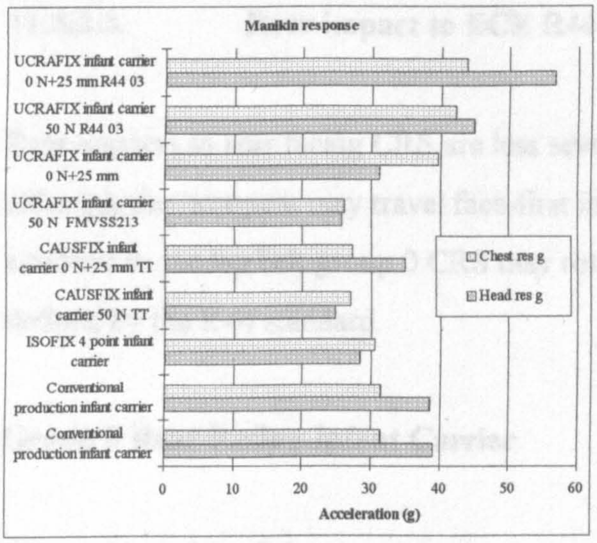


Figure 11.61 Manikin accelerations

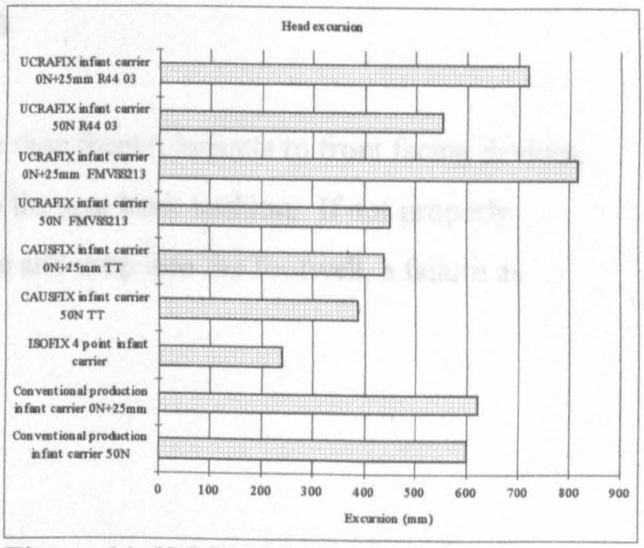


Figure 11.62 Manikin excursions

Group 1 Rear Facing Child Restraint

The variation between the systems and set ups was less evident with the larger heavier Group 1 rear facing Isofix devices. Of the rigidly attached systems, the four point system was again the best, but the performance of the Causfix and the Deutschfix were comparable. The performance of the Causfix was slightly better with increase top tether tension.

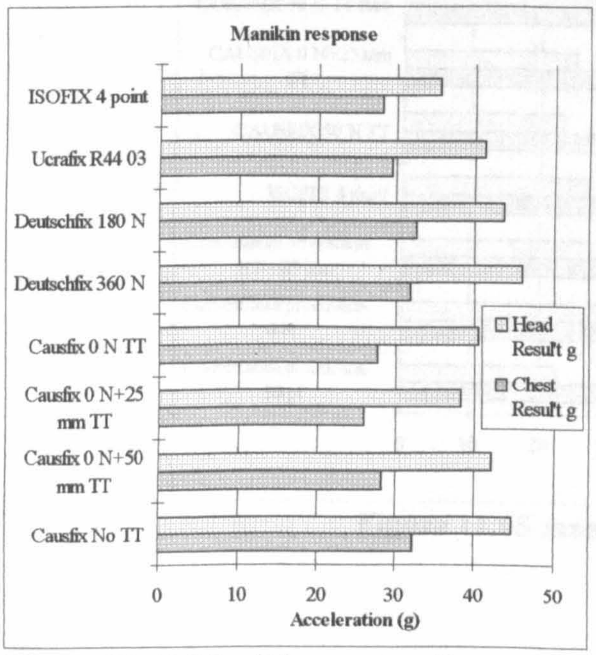


Figure 11.63 Manikin accelerations

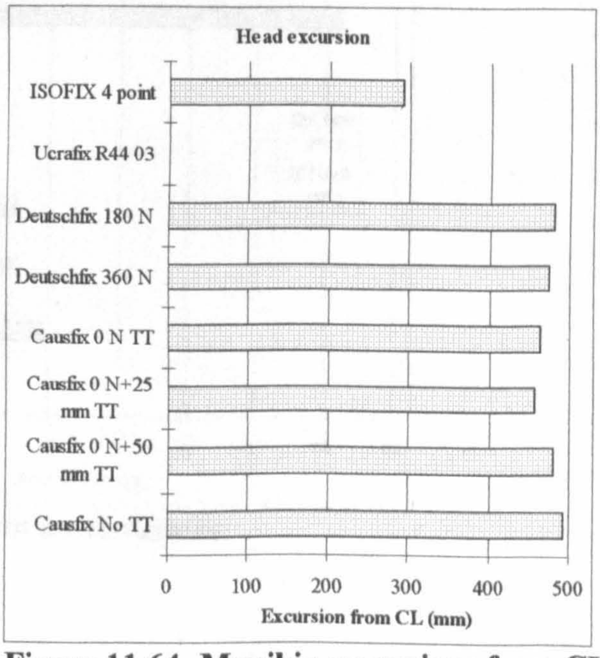


Figure 11.64 Manikin excursions from CL

The greater moment of inertia of the rear facing Ucrafix soft anchor system was sufficient to cause failure of the 1" width webbing with both the FMVSS and R44 anchorage positions. The alternative 1.5" width webbing also failed in one test.

11.3.2.3. Rear impact to ECE R44 03

Rear impacts to rear facing CRS are less severe than frontal impacts to front facing devices, although the occupant may travel face-first into the seat back cushion. If not properly attached to the lap belt group 0 CRS may rotate and drop into the footwell, a failure as defined by the R44 standard.

Group 0 Rear Facing Infant Carrier

The performance of rear facing infant carriers (see figure 11.65) is remarkably similar irrespective of type of restraint system, except for the Ucrafix. The Ucrafix registered a significantly higher head loading (predominately 'x') as the manikin was projected on rebound into the back of the seat.

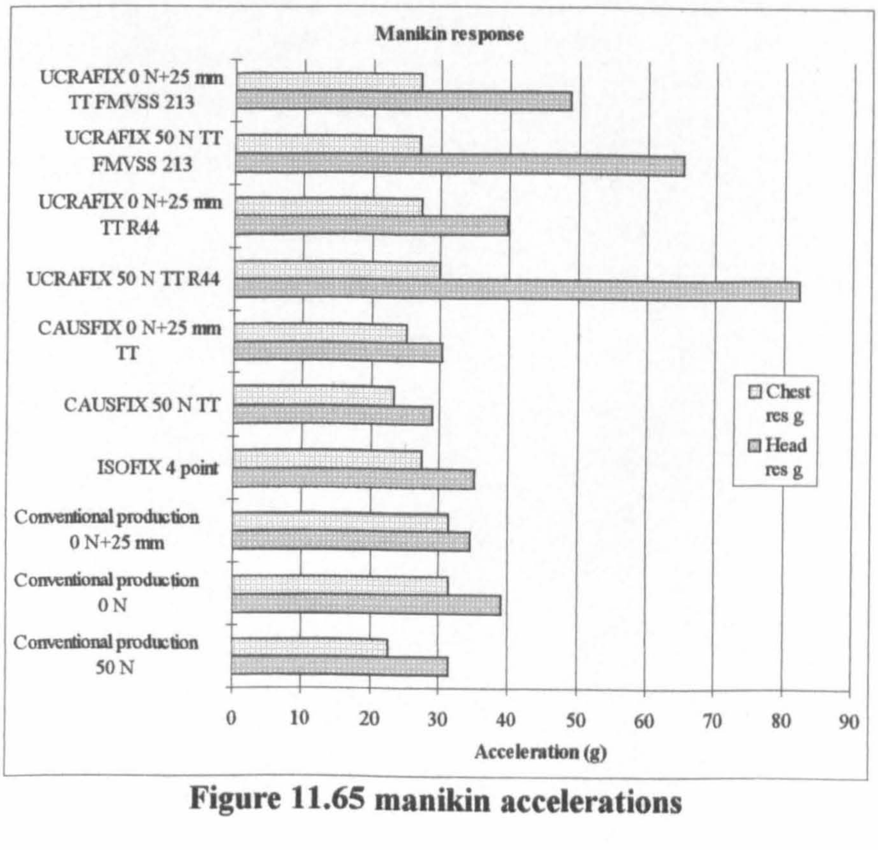


Figure 11.65 manikin accelerations

Group 1 rear facing child restraint

Large rear facing CRS are commonly equipped with a rear tether (RT) to prevent rotation into the seat back. All devices tested were so equipped except the Deutschfix which has a pre tensioning pram handle.

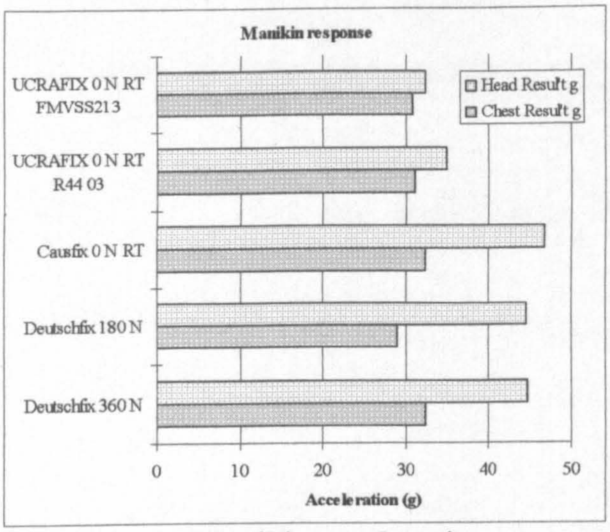


Figure 11.66 Manikin accelerations

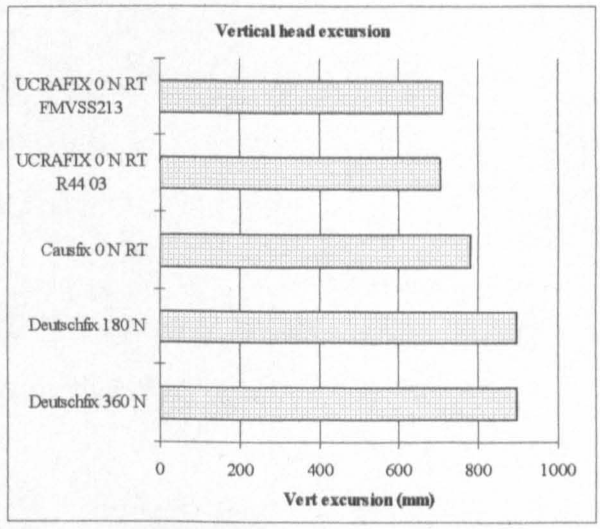


Figure 11.67 Manikin vert excursions

Devices with a rear tether performed slightly better than the pre-compression Deutschfix which distorted slightly under load. All the devices registered acceptable levels of performance, although the Deutschfix exceeded the vertical head excursion limits due to distortion of the pram handle.

11.3.3. Forward facing (Groups 2 & 3) CRS

Only Group 3 booster cushion systems were available for evaluation. Group 2 booster seat (booster cushion with back) Isofix devices were not available. In the circumstances, the review of the general concepts is based on Group 3 test results.

The main concern associated with Isofix Group 2 & 3 devices is submarining as the occupant slides off the front of the cushion section. The Isofix devices tested were confined to those described below plus a conventional booster cushion retained by the lap section of the adult lap and diagonal belt. All the devices were based on the same production booster cushion which was included for comparative purposes.

Scheme A

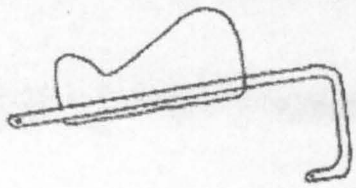


Figure 11.68 4 point Isofix

Scheme B

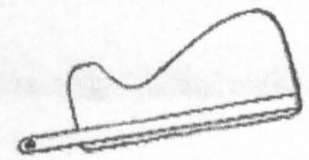


Figure 11.69 2 point Causfix

11.3.3.1. Frontal Impact to ECE R44 03

Testing was conducted according to ECE R44 03 with a P6 manikin to represent a child at the lower end of the mass range recommended for this type of device.

The following table details the significant response data obtained during the tests.

	ECE R 44 Limits	Conventional booster cushion T3017	4 point Isofix booster cushion T3016	Canfix booster cushion T3015
Chest 'z' compressive decel (g)	30.0	17.8	11.2	23.8
Resultant chest decel (g)	55.0	38.4	45.0	39.9
Resultant head decel (excludes contacts) **(g)**	N/A	54.7	80.2	53.6
Head excursion beyond CR point (mm)	550.0	440.0 (1)	376.0	485.0 (1)

Notes (1) : Manikin roll out occurred, left arm almost out of diagonal belt section at max excursion..

A modification has subsequently been allowed to the lateral adult belt 'D' ring location to minimise roll out of the P10 manikin (a problem encountered with the P6 device).

Figure 11.70 Booster seat response

All the booster seat systems met the dynamic requirements of ECE R44 03 despite roll out from the diagonal section of the adult belt. However, both the conventional and Causfix systems would have failed the certification criteria due to 'roll out' and the near disengagement of the left arm from the diagonal belt section at peak head excursion (see ECE R44 03 section 6.2.4 *Explanatory note*).

The roll out phenomenon occurred with the two systems when the booster cushion compressed through the vehicle seat cushion during the dynamic event. This phenomenon is specifically addressed by ECE R44 03 (section 8.1.3.2.1.3.) with respect to a 10 year old occupant (a worst case condition for roll out due to the seated shoulder height). It states that when booster cushions are to be tested with the manikin representing a 10 year old child, the booster can be offset towards the 'D' ring by 75.0 ±5.0 mm relative to the test seat centre line. The effect of this is to allow the diagonal section of the adult belt to be more effectively positioned on the manikins shoulder, thus mitigating roll out. In these tests, as with a vehicle, this would be impractical without rework of the test seat when using the 'rigid' lower anchorages. Similarly, for a standard booster installation, the location of the lap portion of the adult belt protruding from the test seat cushion (R44 03) prevented significant relocation of the booster/occupant towards the 'D' ring.

The problem when testing with a manikin is fundamentally a function of the adult belt anchor geometry on the ECE R44 03 test bench. The 'D' ring location relative to the test seat centre line is too far out board to reflect most passenger vehicles because no allowance is made for the tumble home of the vehicle upper body structure. The current test seat is more representative of a square sided vehicle, such as a Land Rover, rather than the conventional family car. Further it is clear that the construction of the manikin's thorax is not as pliant as that of a child.

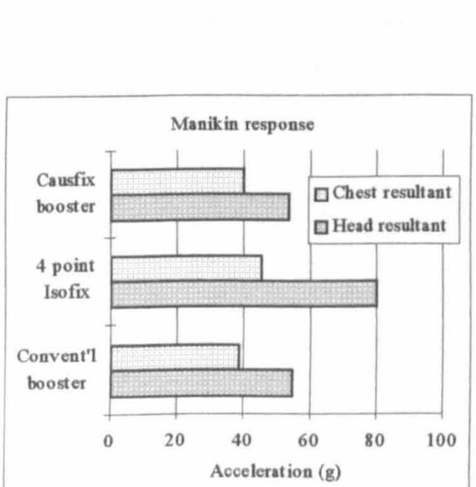


Figure 11.71 manikin accelerations

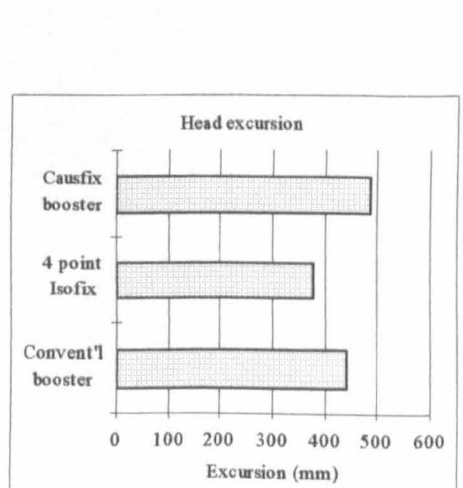


Figure 11.72 Head excursion

It was noticeable that the 4 point Isofix system without roll out produced a markedly lower head excursion but with a slightly higher chest resultant and a markedly higher head resultant deceleration. There were no contacts between head/chest and legs/arms.

In general, the dynamic performance of the Causfix booster, including roll out, appeared no worse than a conventional booster system with the ECE R44 03 test seat cushions. However, the result for the 2 point Causfix booster cushion was felt to be unduly good being obscured by the roll out phenomena (which is considered a function of the manikin's chest structure/stiffness). Had the manikin in the Causfix evaluation not rolled out during the test it is considered likely that the manikin may have submarined due to the rotation of the booster seat about its rear fixings, which results in the anti-submarining feature being effectively eliminated. For this reason it is felt undesirable that a 2 point booster seat/cushion should be pursued.

11.4 Related Isofix Issues

These are detailed in Chapter 14, Discussion.

12. THE EFFECT OF CRS RECLINE ANGLE ON PERFORMANCE IN A FRONTAL IMPACT

During the series of tests described previously (chapter 10) it became apparent that for forward facing Group 1 CRS, the seat inclination angle was determined primarily by 'package' considerations and occupant comfort rather than optimal safety performance. This could apply equally to Isofix and conventional belt retained CRS. When a number of popular conventional CRS were installed on the ECE R44 test seat the CRS seat base inclination angle when measured from the horizontal varied from 30° to 45° in the 'upright' position, and considerably greater with those CRS with recumbent position capability, up to a maximum of 60°.

During the development stage of a new reclining conventional 5 point CRS designed to meet the dynamic requirements of ECE R44 03 it became evident - contrary to expectations - that the upright seating configuration was not necessarily the worst case for forward head excursion in a frontal impact. In contrast it was the full recline position that produced the greatest head excursion with the manikin rotating within the harness about its hips/lower back until contact was made with either chest or legs. Video analysis also showed that the angular velocity of the manikin head about its neck was greatest when in the reclined position with implications for neck loading.

A literature survey revealed very little information on the effect of seat geometry on occupant response in a dynamic event. Janssen et al [7.2/7.3] briefly compared neck loading with a TNO P3/4 manikin when subjected to frontal impacts in accordance with ECE R44, but referred only to a lap belt retained 4-point harness CRS tested in the upright and recline positions.

The need for a more substantial investigation into the loading and dynamic performance was evident to facilitate both the development of current belt retained CRS and to support the work conducted in the field of Isofix.

Initially the Isofix CRS system favoured in the UK was the four point system and the test programme, therefore, was based about a four-point system. The benefit of using a system of this type was that it has no system variables such as adult belt systems and vehicle seat cushions and still offered a potential worst case condition. This condition is possible because the CRS angle of recline to the horizontal does not decrease during the dynamic event as often occurs with a conventional CRS. For these reasons a rigid four-point CRS able to rotate the occupant and seat shell about the occupant's seated centre of mass was constructed. The seat was designed to allow dynamic tests to be conducted with seat base angles of between 0° to 90° to the horizontal, in increments of 10°. The seat shell was a commercially available product that had a seat base to seat back angle approaching 90°; the shell was cut away to provide a clear view of the manikin during the event. Figure 12.1 shows the 'buck' installed upon the standard four-point Isofix mounting fixture with a P3 manikin in place.

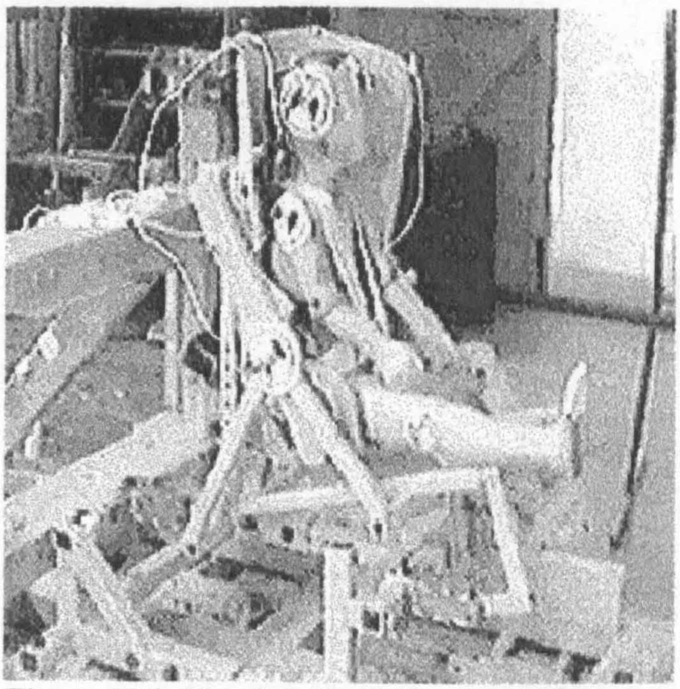


Figure 12.1. Pivoting 4 point Isofix CRS frame.
Note manikin clothed for tests

A series of trials were conducted using the CRS system as described with a TNO P3/4 manikin to represent the youngest child currently recommended for a forward facing Group 1 CRS and with a TNO P3 manikin to represent a child at the opposite extreme also for a Group 1 CRS. Whilst the TNO P range of manikins may have neck structure limitations, they are suitable for the comparative assessment of seat inclination performance.

In addition to the testing conducted on the above buck, a further evaluation was conducted employing conventional belt retained CRS that complied with the requirement of ECE R44 03.

The enhanced occupant protection of rear facing CRS is widely recognised for both infants (Group 0 CRS) and older children (Group 1 CRS). Scandinavian countries in particular favour the rear facing configuration in the front of vehicles for children up to 4 years and older. It seemed appropriate, therefore, to incorporate a similar angle of inclination to the horizontal as a design parameter of a device based on the pivoting 4 point Isofix CRS frame mounted rear facing. A series of tests were conducted with such a device using the TNO P3 manikin. The greater mass of the P3 was considered likely to offer a worst case condition.

12.1. CRS Performance with Varying Seat Angle

This series of tests comprised three parts. Part 1 was conducted with the TNO P3 manikin suitably instrumented for chest deceleration and harness loads in the upper, lap and crotch straps and the translation of body reference points measured from high speed video footage. Part 2 was similar to Part 1 with the addition of a head accelerometer but without the belt load gauges. Part 3 was based on the results of Parts 1 and 2 that indicated the need to determine neck tensile and shear forces and neck bending moment in flexure and extension on both P3 and P3/4 manikins. The part 3 tests repeated those TNO P3 part 1 and 2 tests felt to indicate potential neck load concern, and in addition, evaluated similar parameters where appropriate on the TNO P3/4 manikin. The results as presented are a composite of all three test series. The subsequent section indicates the effect of seat angle on a typical conventional belt retained Group 1 CRS (using the P3 manikin). Where appropriate testing was in accordance with the set up and dynamic requirements of ECE R44 03. The results of the rear facing tests with the P3 manikin are presented for comparative purposes with the forward facing tests.

The results are presented conventionally and, where appropriate, in accordance with ECE R44, with head and chest resultant accelerations and chest 'z' acceleration (from chest to head) being the defining criteria. Although not an acceptance criteria, chest 'z' acceleration from chest away from head is also presented because this parameter is sometimes at least as great as the compressive component. In accordance with data interpretation specified in R44, the acceleration data excludes 3 millisecond exceedances.

Motion of the manikin extremities are the total movements (target to target) of the head, shoulder and hip both vertically and horizontally and differs from R44 where only head excursion is recorded. ECE R44 defines excursion as the peak distance travelled by the head of the manikin beyond the CR point of the test seat. For this series of tests with a pivoting seat it was impractical to quote head excursion because when in a significant recline attitude the manikin's head is initially behind the back of the test R44 test bench. Since test data were for comparative purposes, it was considered acceptable to present the total head travel.

The belt loads quoted are gauge peak values which do not necessarily occur simultaneously. Similarly, neck loadings - shear, tension and bending - do not peak simultaneously. The neck load data is presented both as peak values and in a form as presented by Janssen et al [7.2] excluding 30 millisecond exceedances.

12.1.1. Seat Angle Evaluation Forward Facing Isofix 4 Point (Group 1 CRS) P 3 Manikin

Travel/excursion of manikin body targets

Figures 12.2 and 12.3 show the horizontal and vertical travel of the manikin head when subjected to dynamic testing to the requirements of R44 (with standard 25 mm harness slack). Excursion, target centre to centre, is shown for seat base inclinations to the horizontal. A seat base inclination of 0° to the horizontal refers to a horizontal seat base, and vertical seat back (figure 12.1.) and a seat back inclination 90° to the horizontal refers to a vertical seat base and horizontal seat back with the manikin lying on its back.

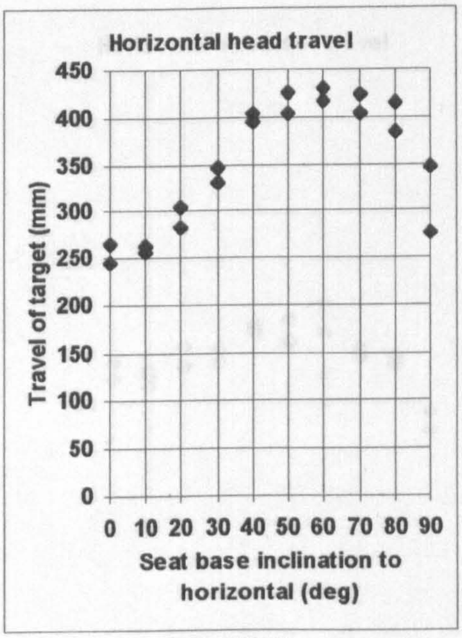


Fig 12.2

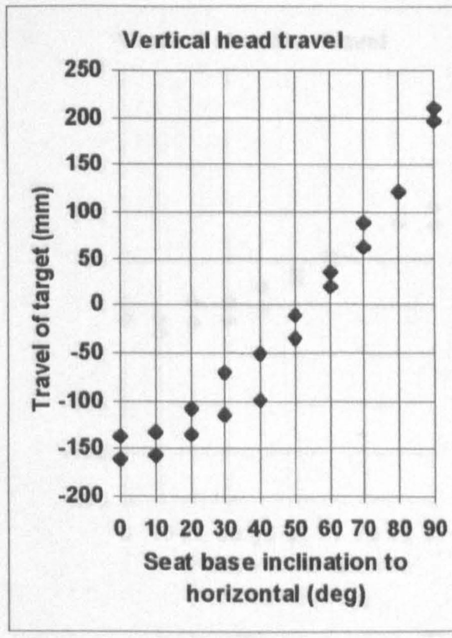


Fig 12.3

The horizontal head excursions clearly show, as expected, that the head travels further forward with increasing levels of seat recline, with maximum travel between 50° and 70°. At these recline angles the forward travel on this 4 point Isofix system of approximately 425 mm is in the order of 23% greater than in the conventional upright CRS configuration when installed in a vehicle (typical seat base 30° to the horizontal) of approximately 345 mm. If we take as a baseline the slightly unrealistic condition of a seat base at 0° to the horizontal, the travel at 60° to the horizontal can be seen to be up to 80% greater. It is reasonable to expect these horizontal travel results to be reflected in head excursion as defined in R44, since the head start position would essentially be the same in any realistic recline position, normally close to the top of the vehicle seat back. Current retail reclining CRS tend to pivot from a point at the top of the seat back close to the occupants head, facilitating the market requirement of moving the CRS from upright to full recline (some with intermediate positions) without re-tensioning the adult belt that attaches the CRS to the vehicle seat. Thus to move the CRS to the recline position involves moving the lower body up and forward rather than the head back and down.

Figures 12.4 and 12.5 illustrate a similar if less pronounced travel effect at the shoulder; the shoulder being closer than the head to the hips/lower back, about which the upper torso pivots.

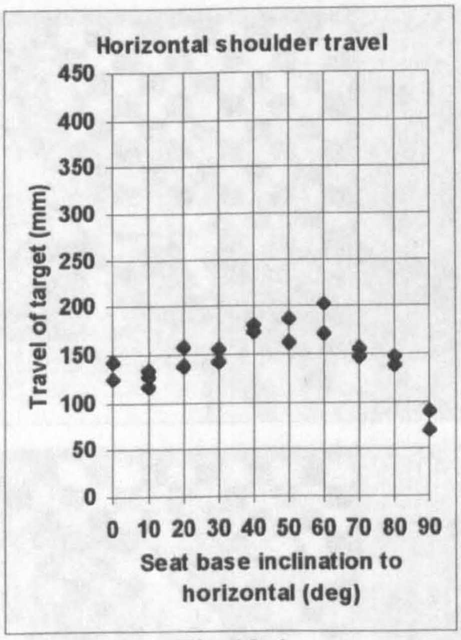


Fig 12.4

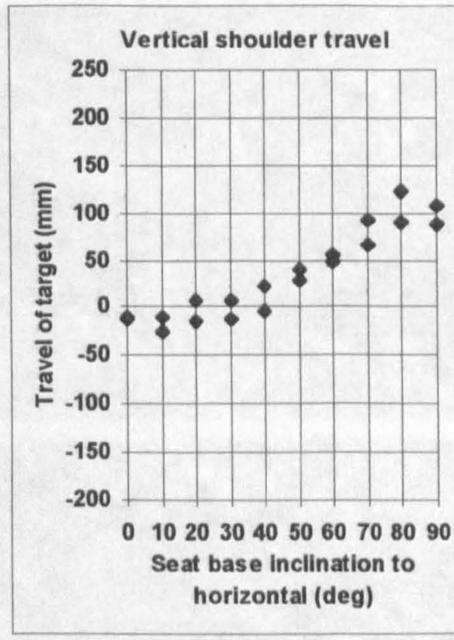


Fig 12.5

Hip travel (figures 12.6 and 12.7) is controlled far more closely by the lap section of the harness. Horizontal travel being greater, as one might expect with lower levels of CRS recline, notably worse at 10°-20° recline.

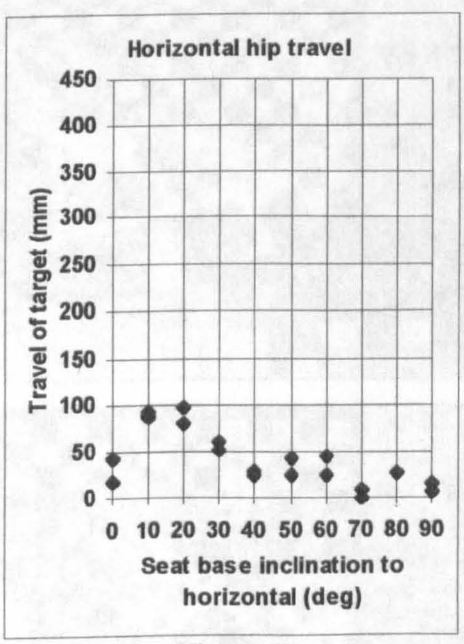


Fig 12.6

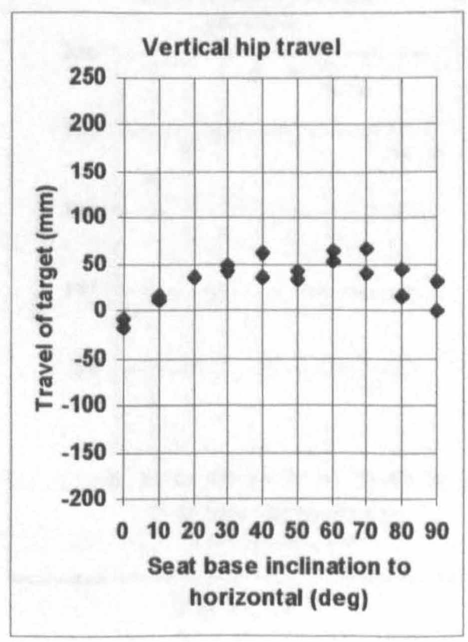
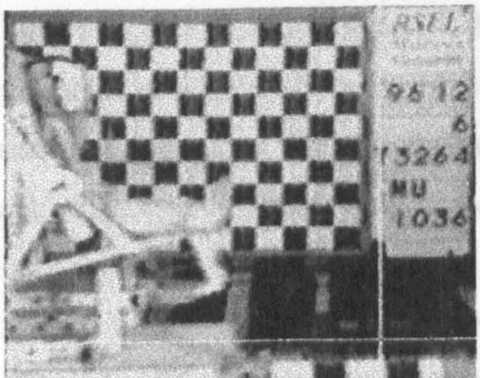


Fig 12.7

Figures 12.8 - 12.10 show the manikin prior to impact and at peak head excursion, for seat inclinations of 0°, 30°, and 60° respectively.



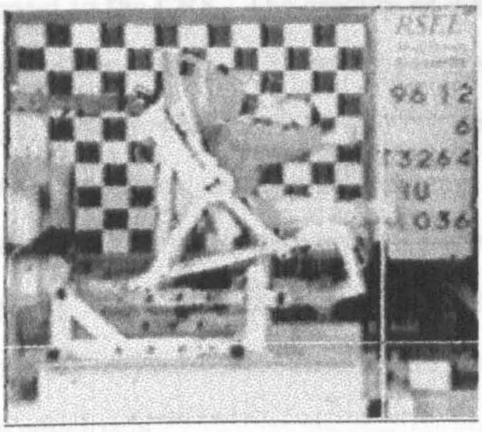
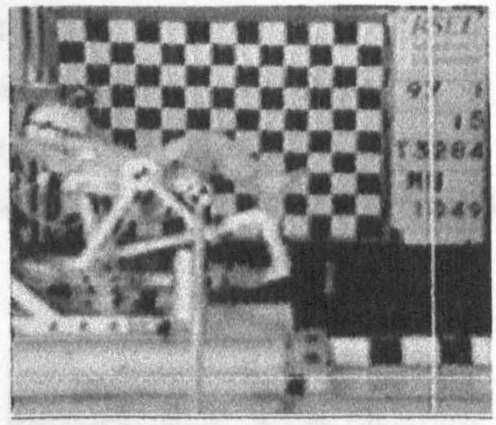


Fig 12.8 0^{o} seat inclination



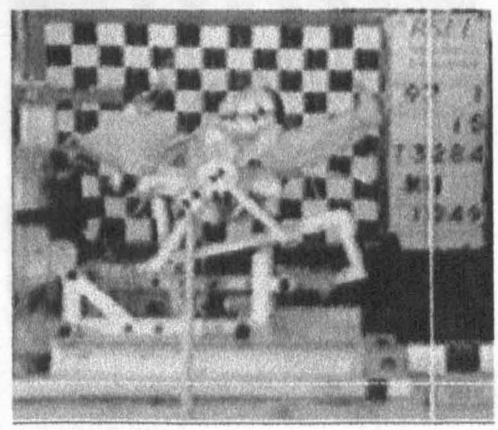
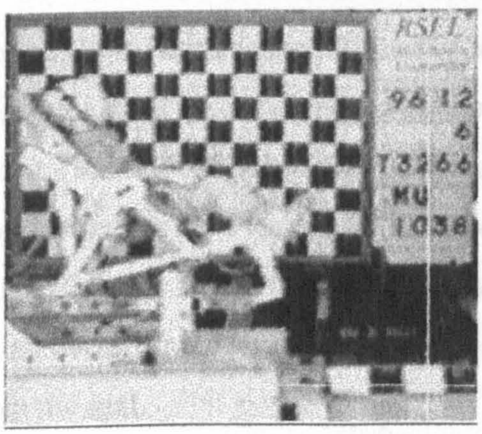


Fig 12.10 60^{o} seat inclination



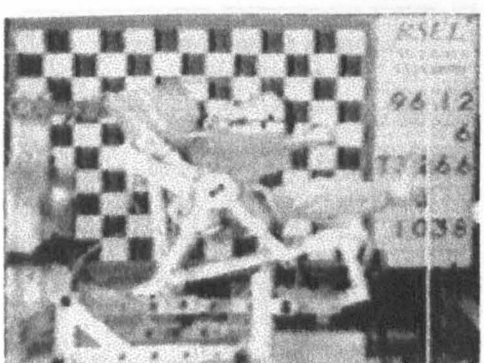


Fig 12.9 30^{o} seat inclination

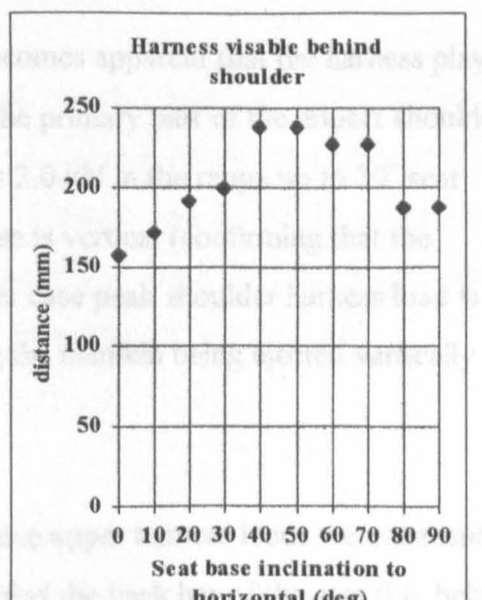


Fig 12.11

In figures 12.8 to 12.11 it is apparent that the increased head travel is the result of upper torso rotation within the harness. However, the torso angle to the vertical at peak excursion appears very similar in the cases shown, it being the initial start position that varies. Figure 12.11 indicates the amount of webbing visible between the seat shell and the point at which it contacts the manikin's shoulder at peak head travel, reflecting the torso rotation with respect to the CRS. The amount of webbing visible increases up to a seat base incline angle of approximately 50°, whereupon rotation declines. Further rotation is prevented by contact between head/chest and legs (fig 12.12 highlights this at the extreme seat base inclination condition of 90°).

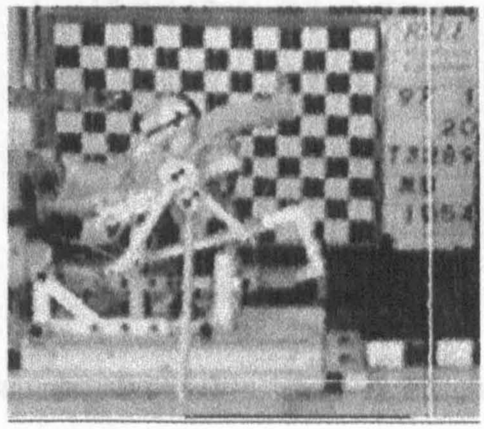


Fig 12.12

Harness loads

Above a seat base angle of 30° to the horizontal it becomes apparent that the harness plays a decreasing role in restraining the occupant. During the primary part of the impact shoulder harness loads (fig 12.13) fall from a peak of just over 2.0 kN in the range up to 30° seat base inclination, to a low of 0.4 kN when the seat base is vertical (confirming that the manikin rotates within the upper harness). In the later case peak shoulder harness load is found during the latter part of the impact, preventing the manikin being ejected vertically from the seat.

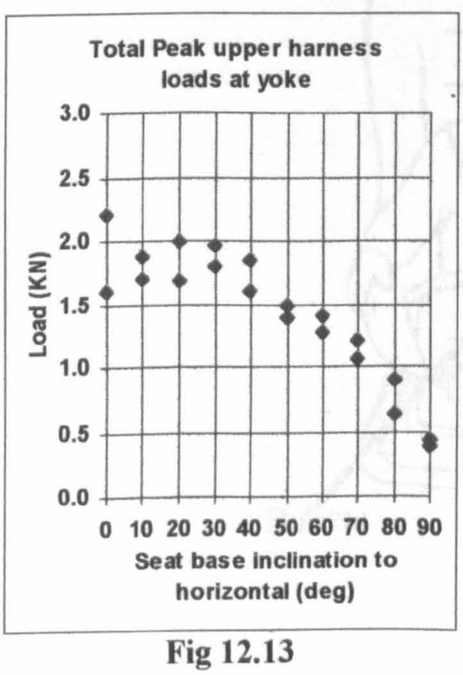


Fig 12.13

These upper harness loads were measured behind the back bar of the seat (i.e. behind the seat shell) the load cell being so located to prevent damage. Subsequent investigation revealed that significant friction between the back bar and the shoulder straps resulted in loads in the order of 30% greater being evident in the shoulder strap ahead of the shell/back bar.

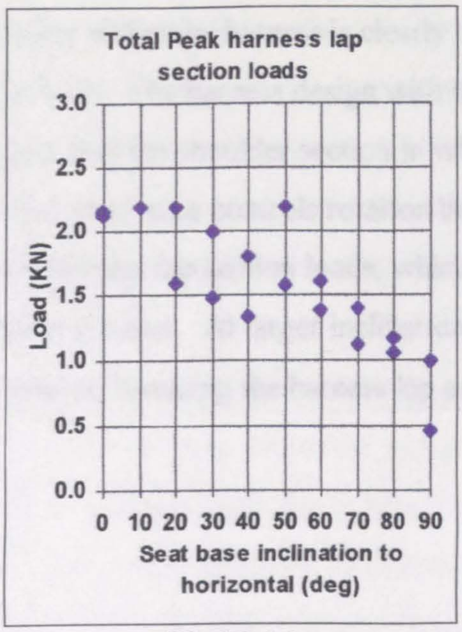


Fig 12.14

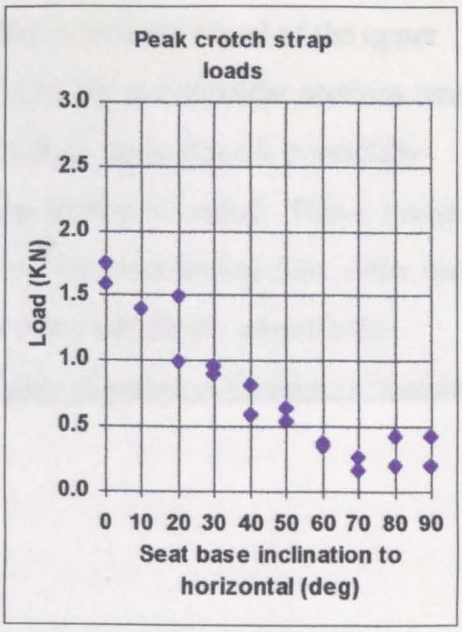


Fig 12.15

Results (figures 12.14 and 12.15) indicate that the lap portion of the harness and the crotch strap become less prominent as the primary restraining medium with the load falling from the order of 2.2 kN total and 1.6 kN respectively to below 1.0 kN and 0.5 kN as seat base inclination to the horizontal increases.

The harness type employed in all the pivoting seat tests was the single pull type common on many modern forward facing Group 1 CRS, offering both simplicity and convenience of adjustment to the user. These employ a single length of webbing each side, forming both the lap and shoulder sections, with a sliding loop at the buckle which is attached to the shell by the crotch strap (figure 12.16 details a typical single pull harness).

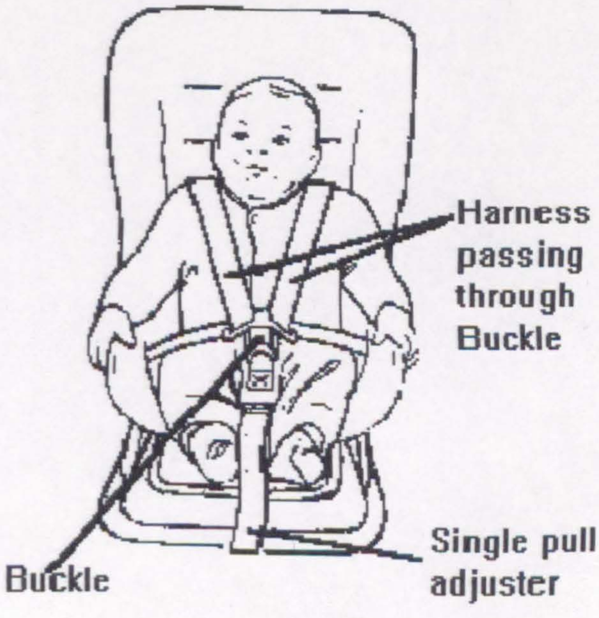


Fig 12.16

Rotation within the harness is clearly a significant factor in forward travel of the upper torso/head. The harness design with sliding loop between lap and shoulder sections would suggest that the shoulder section in which the torso rotation takes place is potentially shorter, and hence controls rotation better when the lap section is loaded. This is borne out by the harness lap section loads, which are higher at low seat base inclinations, when torso rotation is lower. At larger inclinations, the seat base more effectively controls hip translation, lowering the harness lap section load and may allow more harness to pass into the shoulder section. However, video analysis failed to measure any significant differences in upper harness length due to low image resolution, the 3 dimensional nature of the harness run, and the small dimensional differences sought. It is suggested that some repeat testing with the older one piece harness design incorporating separate lap/shoulder adjustment (with sewn joints) may provide a clearer understanding of the suggested effect.

Resultant deceleration levels

The deceleration levels observed reflected the travel data with chest resultant deceleration being greater in the region of increased recline (fig 12.17). Video examination shows that with increased recline angle the upper torso increasingly rotates within the harness about the lower back/hips until the chest/head contacts the legs. This contact is confirmed by the peak chest 'x' data (fig 12.18).

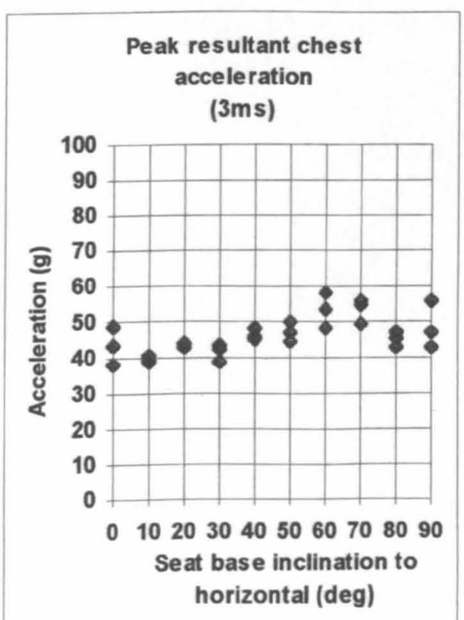


Fig 12.17

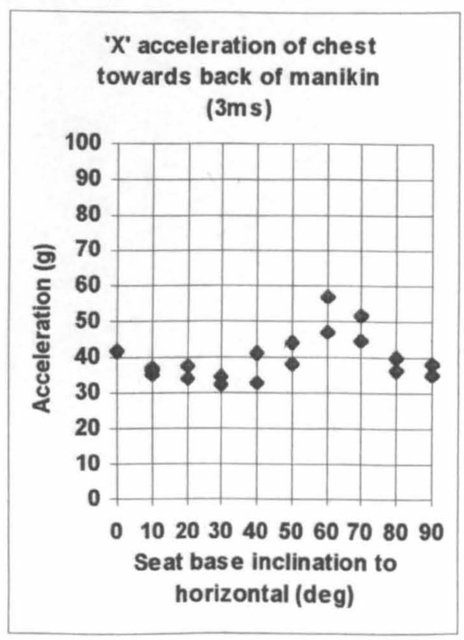


Fig 12.18

The resultant head deceleration (fig 12.19) increases above a 40° recline angle, however the data is recognised as less reliable due to the limitations of the TNO P3 neck construction and the potential for head contacts. With increasing seat base inclination the seat base loading increases, as indicated by the manikins chest 'z' deceleration component, which increases significantly once the seat base inclination rises above 60° (figure 12.20). The R44 acceptance limit is 30g

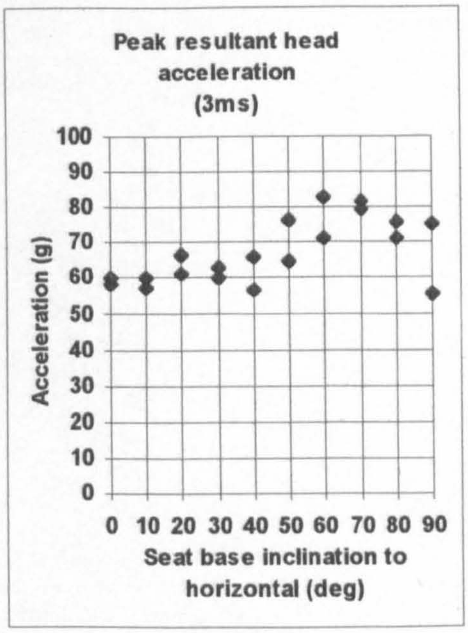


Fig 12.19

Along with this rise in compressive spinal load, tensile spinal load also shows a tendency to increase with seat base inclination as the manikin rotates later in the event, then reducing as rotation diminishes with excessive seat base inclination, as the torso strikes the legs.

Figures 12.20 & 12.21 detail this tendency, figure 12.22 clarifies the accelerometer orientation.

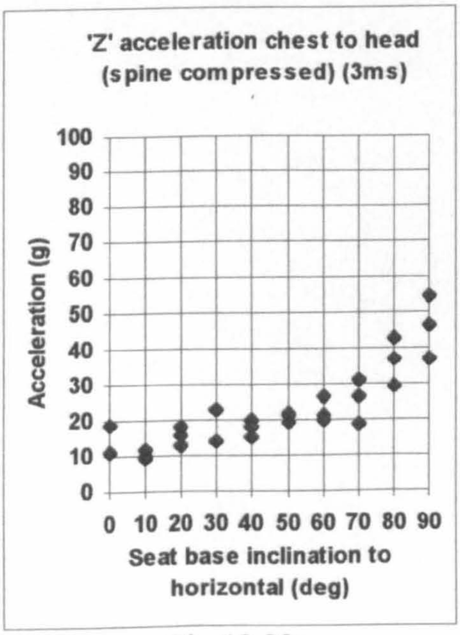


Fig 12.20

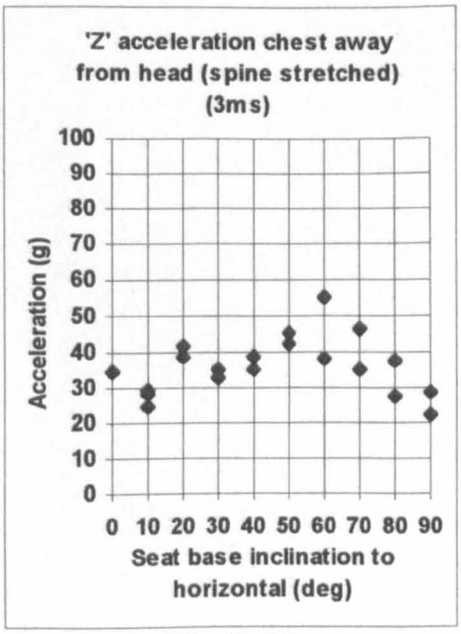


Fig 12.21

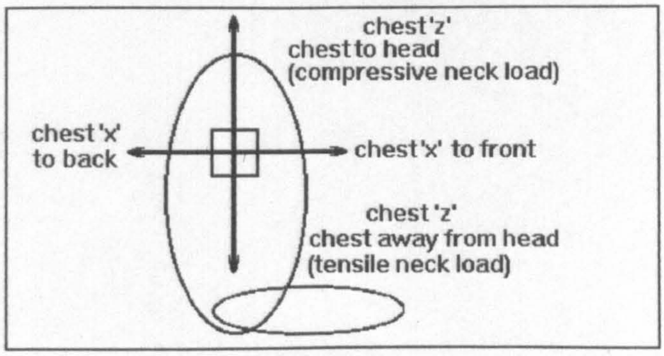


Fig 12.22

Head angular velocity

As previously stated, observations of conventional CRS in upright and reclined configurations indicated that the manikin's head appeared to travel from neck extension to flexion more rapidly with increasing seat recline. To attempt to quantify this, the angular displacement of the head was plotted against time from impact using the high speed video footage of the 1st and 2nd series of these 4 point Isofix tests. Figures 12.24-12.33 show the response at each recline position for the series 1 tests, a similar response was obtained in the 2nd series. Figure 12.23 below indicates the head orientation in the tests, the centre being upright, (0° or 0 rad), the left hand head being in neck extension, (<0° or < 0 rad), the right hand being in flexion, (>0° or > 0 rad).

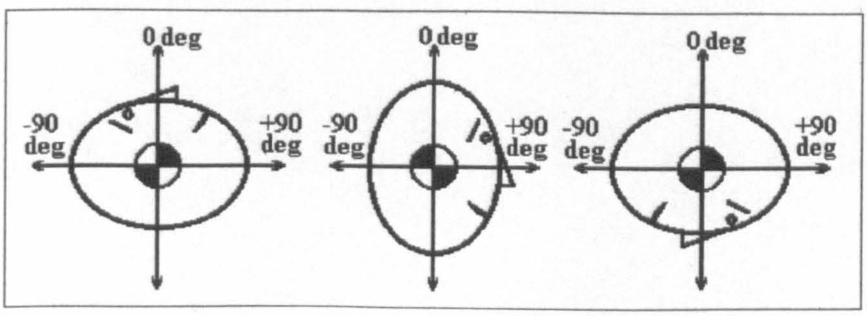


Fig 12.23

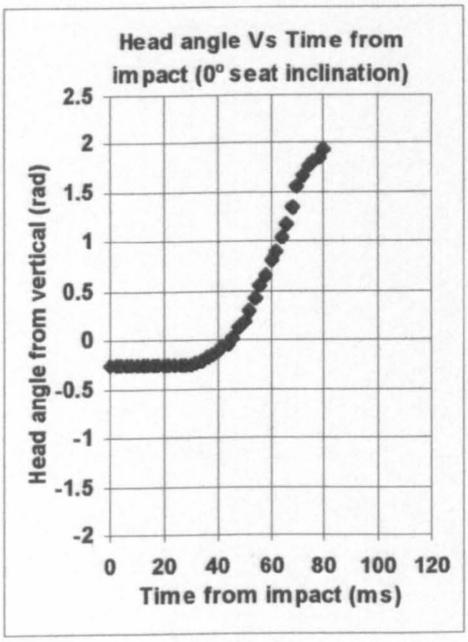


Fig 11.24

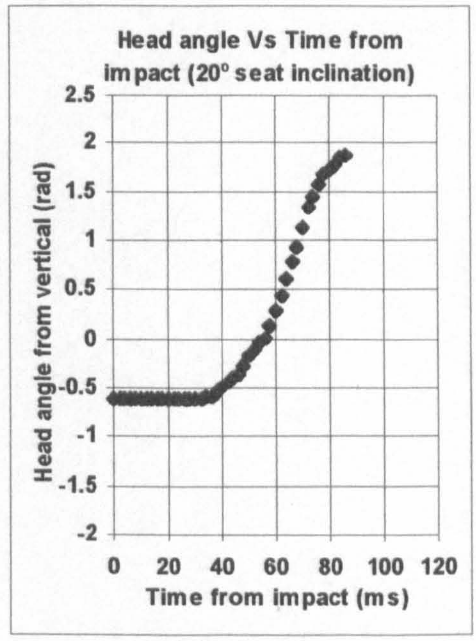


Fig 12.26

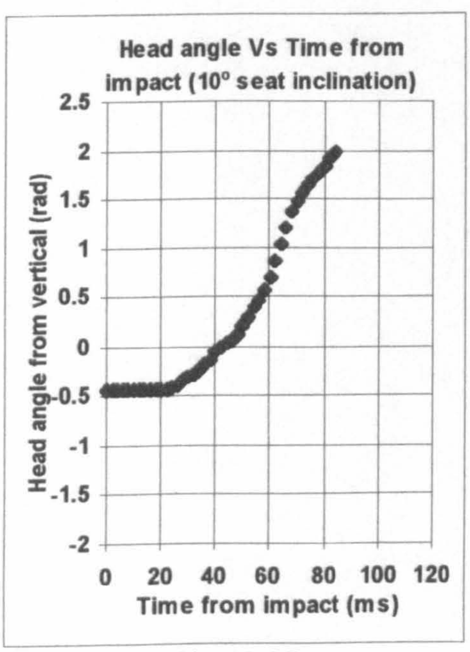


Fig 12.25

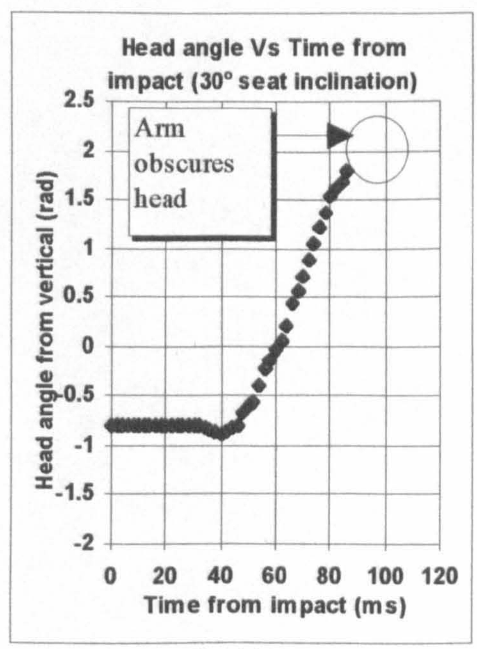


Fig 12.27

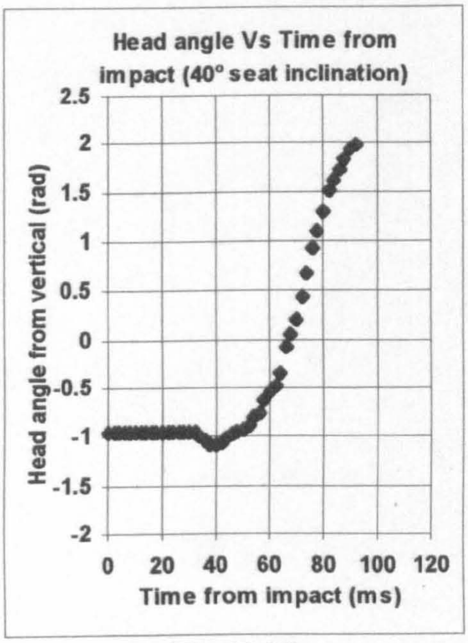


Fig 12.28

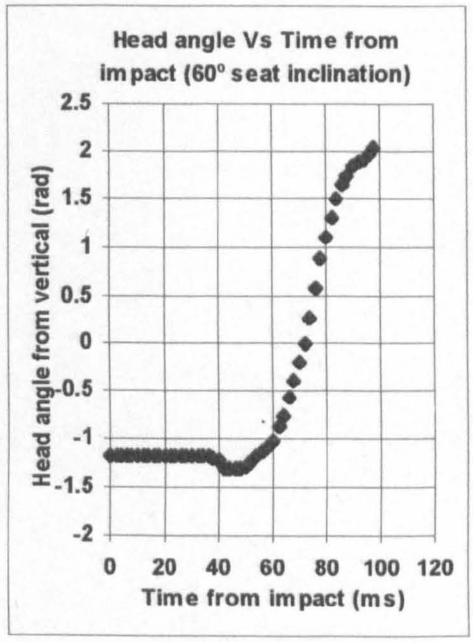


Fig 12.30

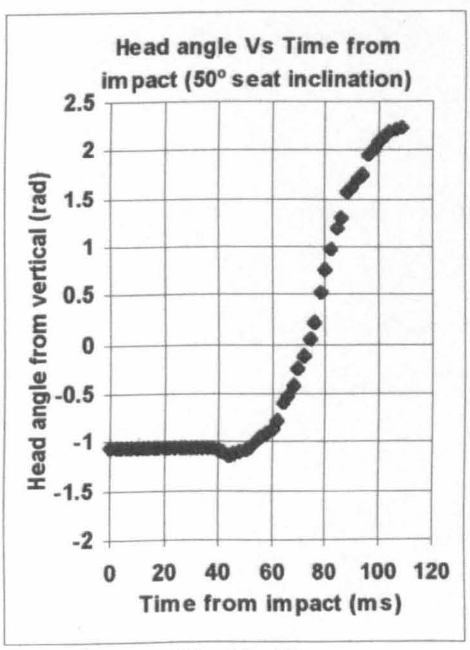


Fig 12.29

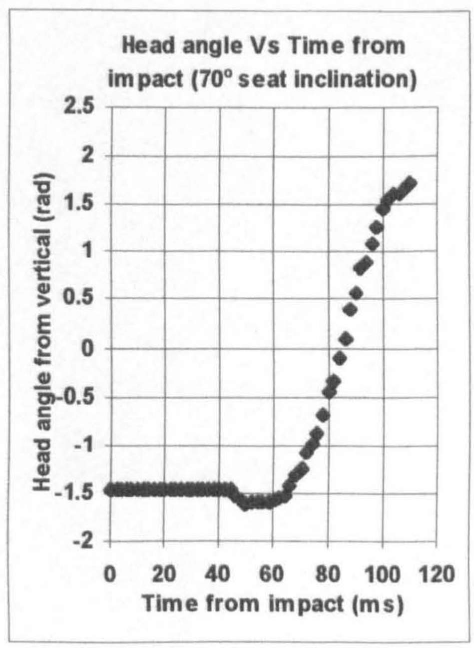


Fig 12.31

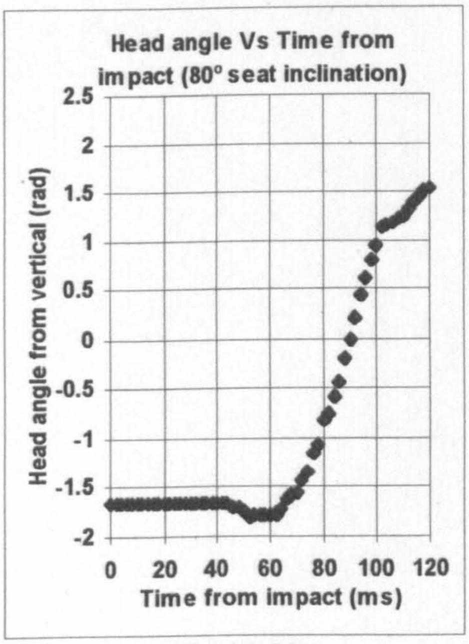


Fig 12.32

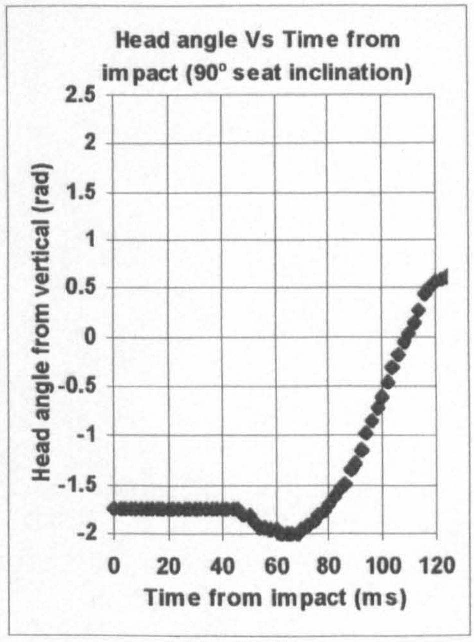


Fig 12.33

Peak angular velocity of the head was obtained from the slopes of figures 12.24 to 12.33, and is shown for both series of tests in figure 12.34. It should be noted that the velocity is measured in the period before any contact with the legs (it can be seen from the above traces that above 50° recline contact starts to be made at the end of the traces). A further point worthy of note is the tendency above 20° seat inclination for the neck to be forced increasingly in to extension at the beginning of the impact, before the head rotates into a neck flexion condition. This phenomena can be attributed to the construction of the manikin's neck, and the location of the centre of mass of the head with respect to the upper neck (atlas/axis block) joint. As the seat is reclined, the centre of mass falls with respect to the neck/head joint, until it is effectively below the pivot, resulting in the head rotating initially in to a neck extension condition. This continues until the mass of the less well retained upper torso (the centeroid of which is above the lap belt/hips), causes the upper body to commence to rotate about the lower spine, bringing the unsupported head with it. The chest starts to be retained as it rotates within the upper harness, allowing the unsupported head to rotate and the neck to go into a flexion condition. Whether this is a particular function of the TNO P type manikin neck construction, or whether to an extent this effect is seen in children where the neck construction is far more complex is at present unclear.

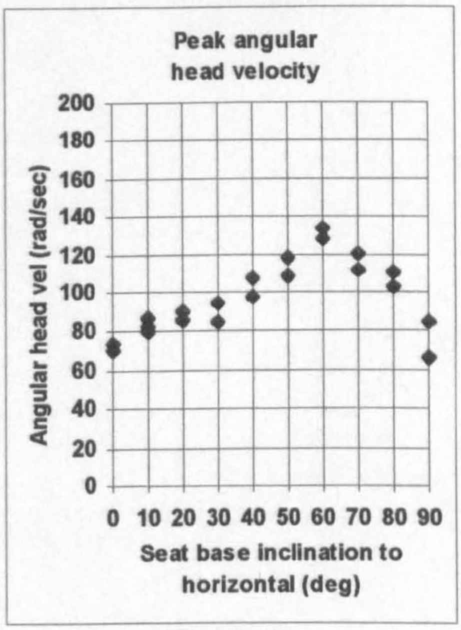


Fig 12.34

It can be seen from figure 12.34 that it is at 60° that the peak value of angular head velocity occurs, being some 40% greater than that which is evident at 30° seat inclination. To attempt to clarify the potential implications of the above data with respect to neck loading the 3rd series of repeat tests were conducted with the installation of a TNO 3 channel load cell in place of the P3 neck atlas/axis block.

<u>Neck loads</u>

The neck load transducer employed measures both shear force F_x, and tensile force F_z, in addition to the fore/aft bending moment M_y on the midsagittal plane at the atlas/axis block (i.e. upper neck). It should be noted that due to the location of the effective pivot on the atlas/axis block with respect to the neutral axis of the load transducer, a calculation based on the displacement is required to obtain the actual neck bending moment M_b.

$$\mathbf{M_b = M_y + 0.008\ F_x + 0.010\ F_z\ (N\ m)} \qquad \textbf{Equation 1}$$

The following figures 12.35-12.44 detail the effect of seat base inclination on neck loading.

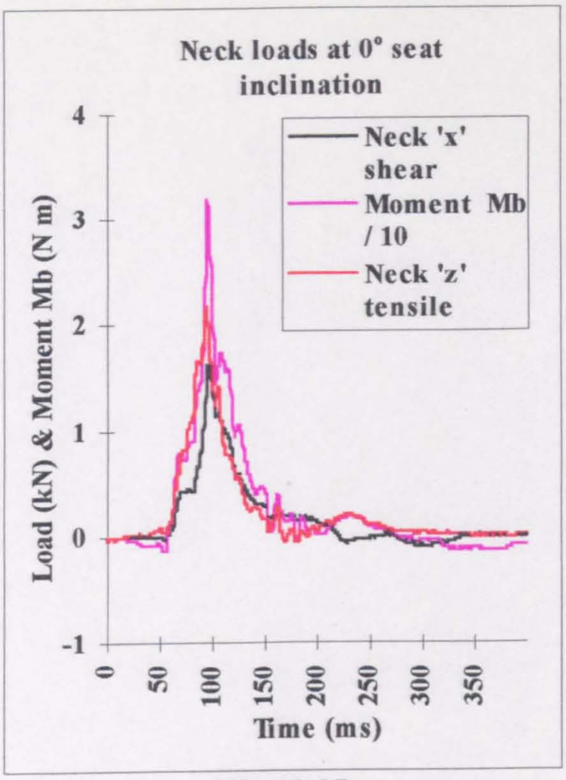


Fig 12.35

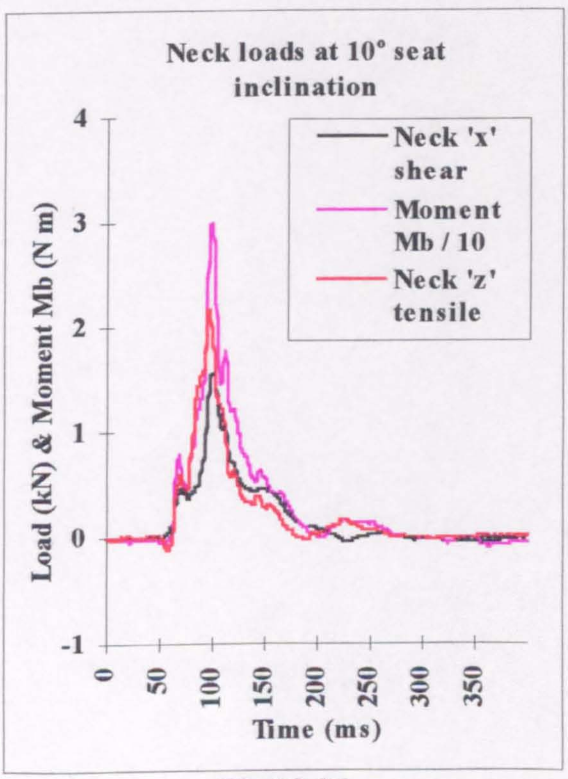


Fig 12.36

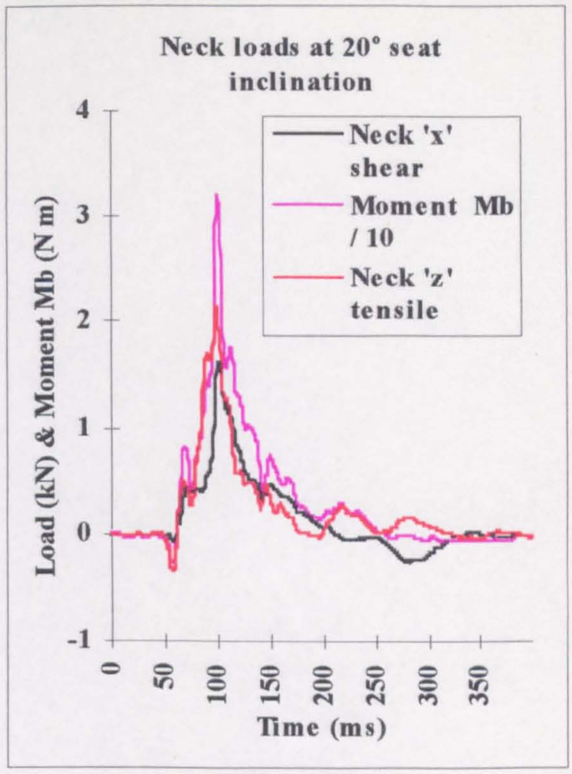


Fig 12.37

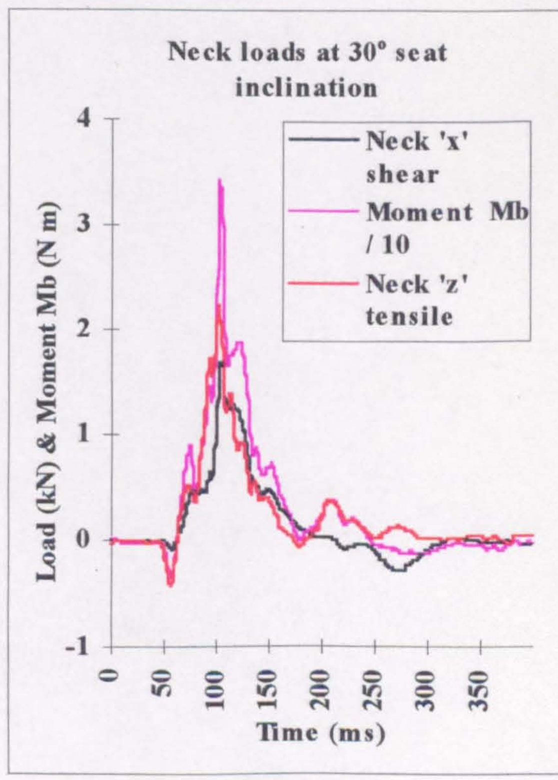


Fig 12.38

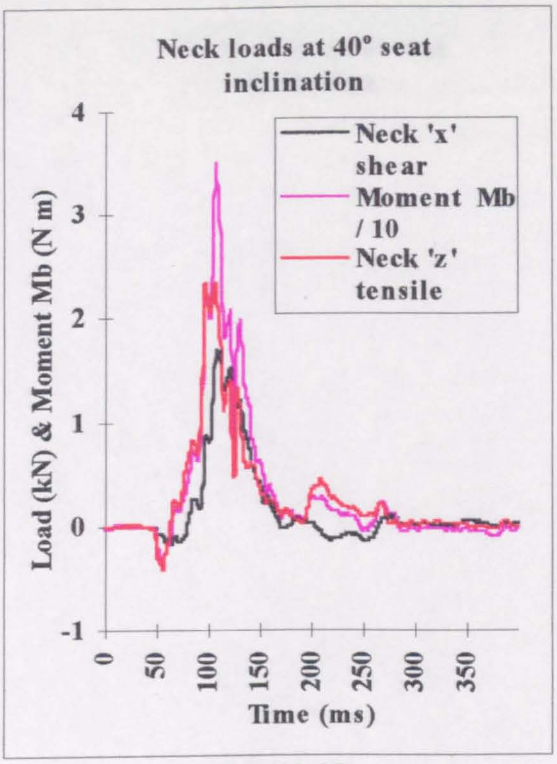


Fig 12.39

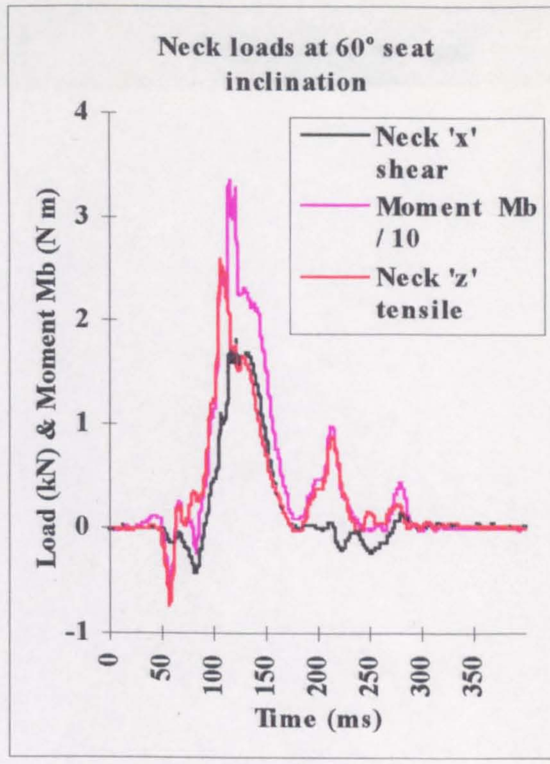


Fig 12.41

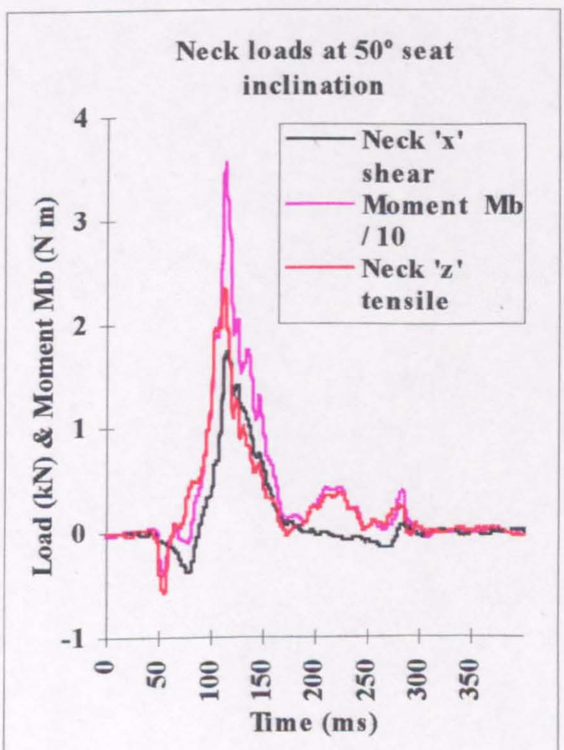


Fig 12.40

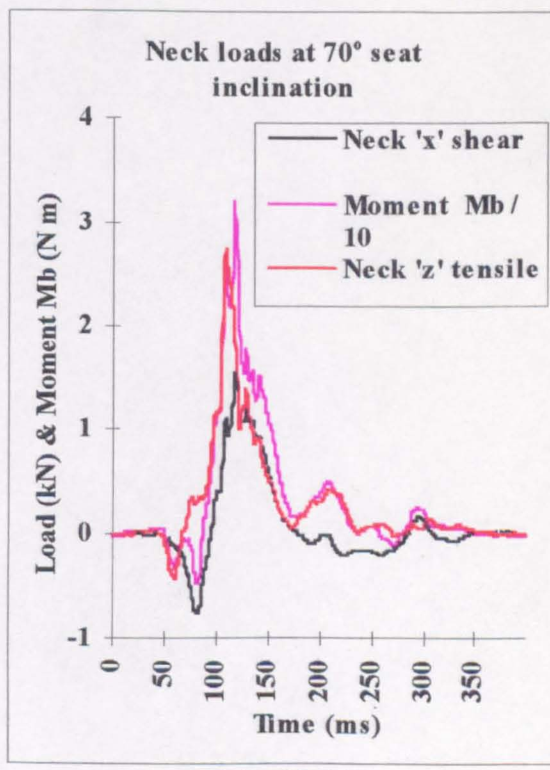


Fig 12.42

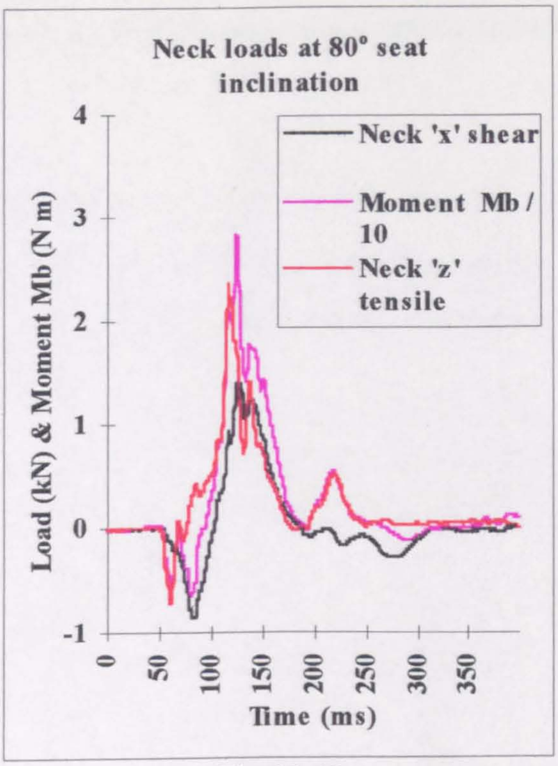


Fig 12.43

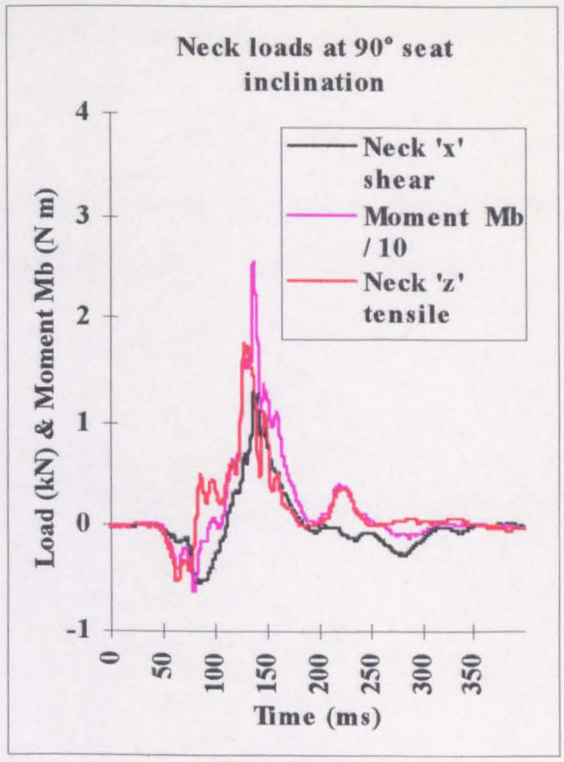


Fig 12.44

The neck extension effect at the beginning of the reclined impacts can be clearly seen and quantified from figures 12.35-12.44. It is apparent that as anticipated it is of far less significance than the later neck flexion component, the peaks of which are shown below in figures 12.45 and 12.46. These detail the effect of seat inclination on shear load F_x and Tensile load F_z respectively. Both the peak, and the 30 ms exceedance values are given.

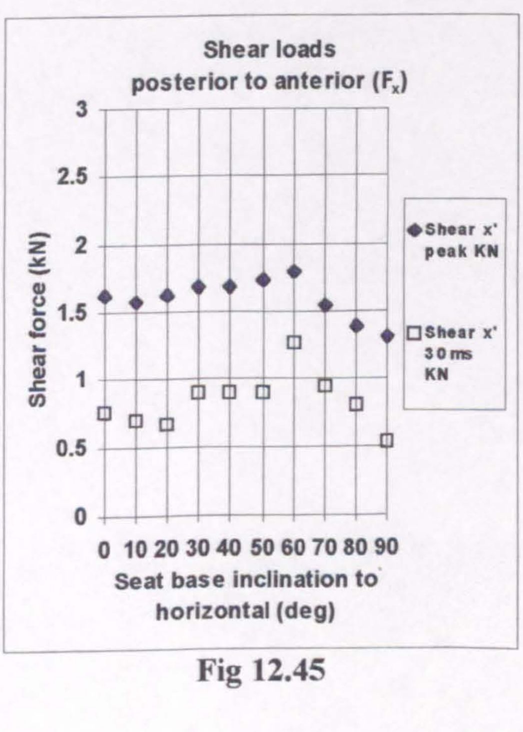


Fig 12.45

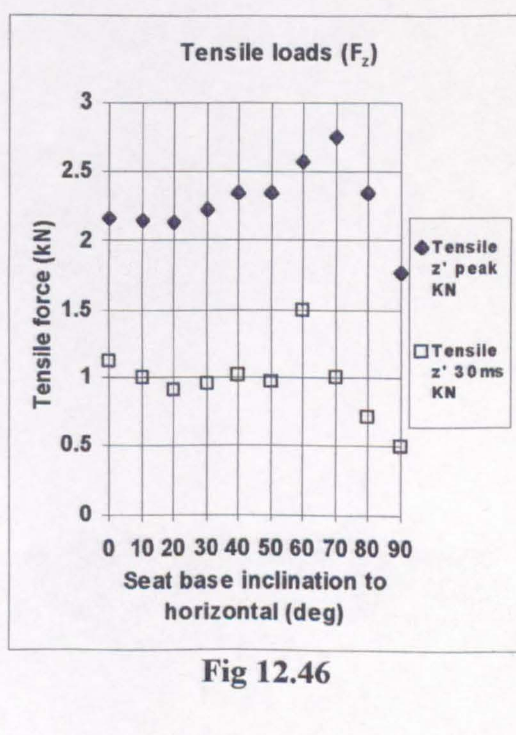


Fig 12.46

It is again apparent that the tensile and shear values follow the trend of increasing with recline up to 60°-70° position.

The following figure 12.47 indicates the fore/aft bending moment M_y in neck flexion on the midsagittal plane observed at the varying seat inclination angles. The peak values occur when the neck is at the maximum flexion condition

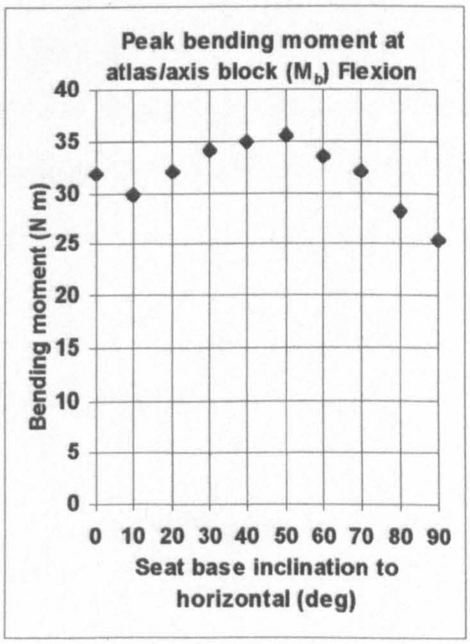


Fig 12.47

What these neck load values mean in reality is not clear. Firstly, these values have been obtained with a single manikin type, incorporating a simple neck structure comprising 1 g atlas/axis joint and a given spine tension. Other manikin types, incorporating more rigid rubber necks affixed directly to the head are available, but little comparative data is available to be drawn upon. Of those data which are available, Janssen et al [7.2/7.3] indicated that both the tensile and shear forces generated at the upper neck of a TNO P3/4 manikin was significantly reduced when the atlas/axis joint was locked up, but that the bending moment increased.

12.1.2. Seat Angle Evaluation Forward Facing Isofix 4 Point (Group 1 CRS) P 3/4 Manikin

Head travel

Figure 12.48 details horizontal head travel of the P3/4 manikin, when subjected to dynamic testing conforming to the requirements of R44 (25 mm harness slack). The displacement, target centre to target centre, is shown versus seat base inclination to the horizontal. The P3/4 manikin can be seen to follow a similar trend to that seen with the P3 manikin. However due to manikin mass and proportion differences the magnitude is slightly lower. The peak horizontal (target to target) travel being evident at around 50°-60° seat base inclination as with the P3 manikin.

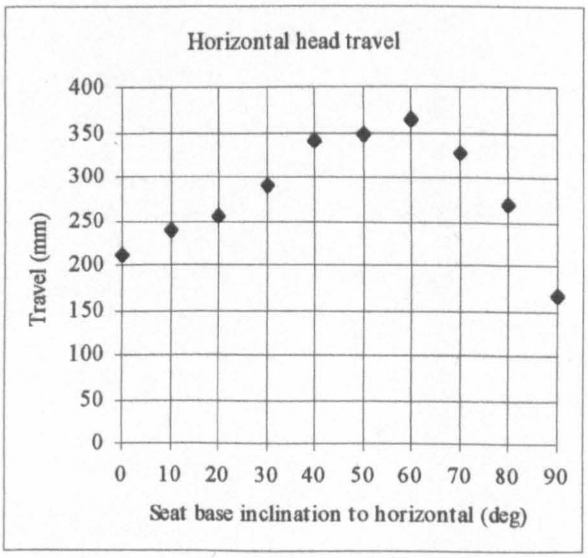


Figure 12.48 Horizontal manikin head travel

Harness loads

Due to instrumentation limitations it was not possible to measure harness loads in addition to neck loading, hence in this series of P3/4 manikin tests harness loads were omitted.

Resultant deceleration levels

The manikin response in terms of peak deceleration levels was not as clear as those seen when the P3 manikin was assessed, being lower in magnitude due to the lower mass.

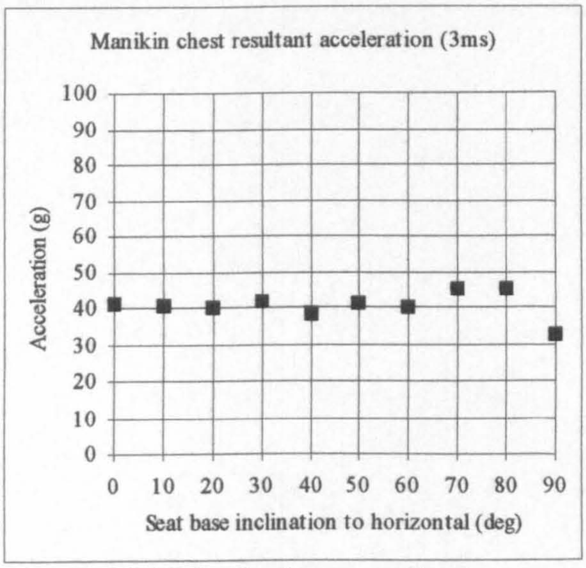


Figure 12.49 Peak chest resultant

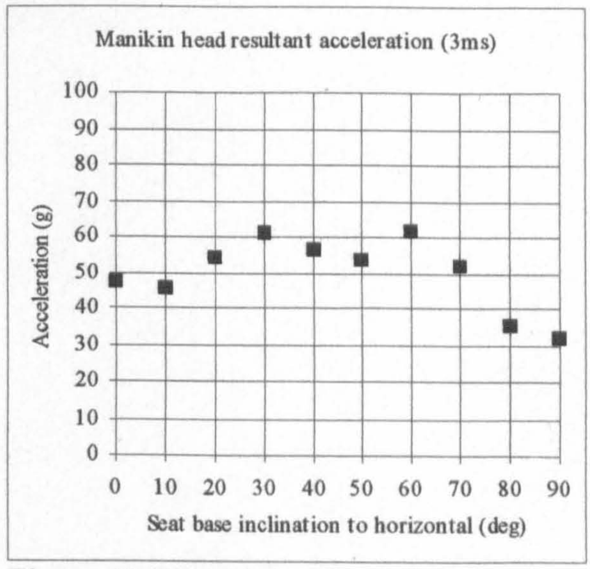


Figure 12.50 Peak head resultant

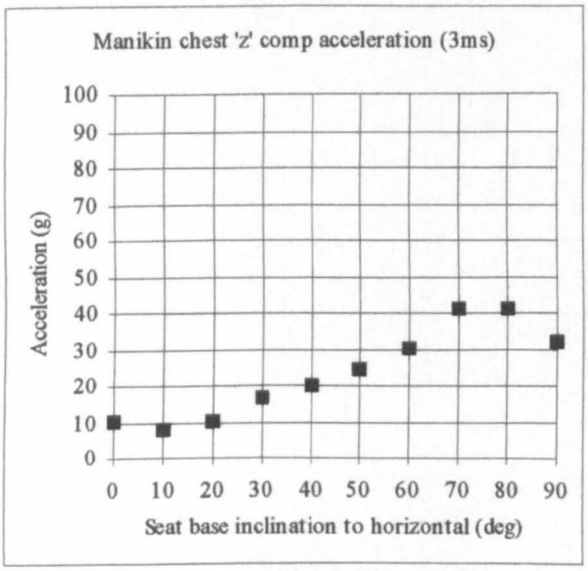


Figure 12.51 Peak chest 'z' compressive

The ECE R44 03 acceptance criteria were again met in all cases, except for the chest 'z' requirement once seat base inclination approached 60° to the horizontal, where the 30 g limit began to be exceeded.

Neck loads

The response of the P3/4 manikin in terms of neck loads was again not unsurprisingly similar to the response obtained with the P3 device, once more lower in magnitude due to the lower mass of the body segments involved.

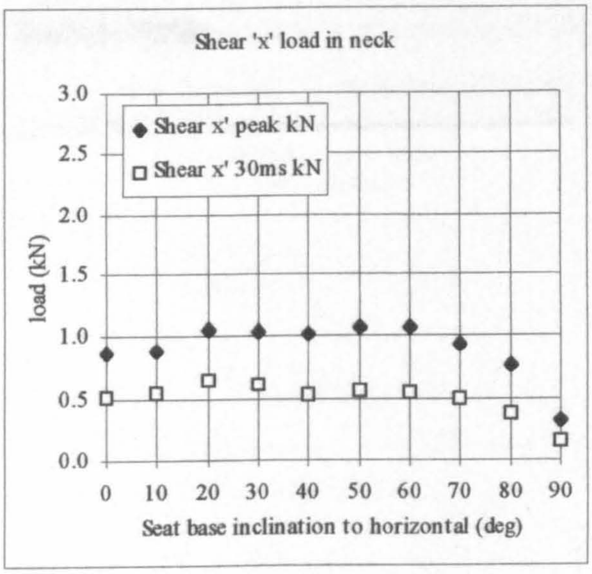


Figure 12.52 Peak shear load at atlas axis

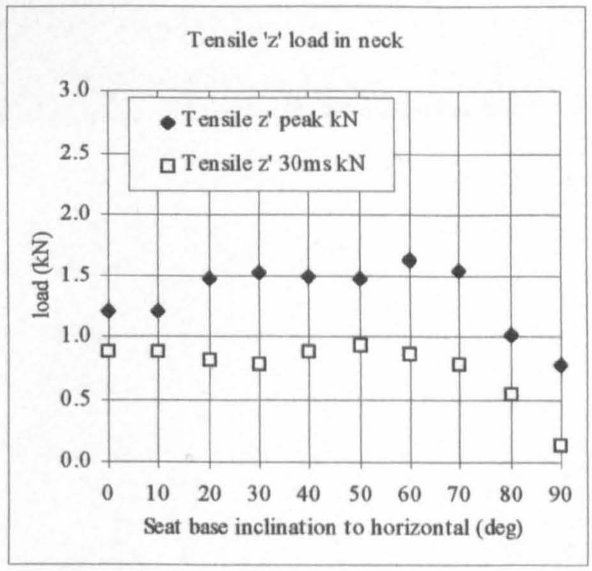


Figure 12.53 Peak tensile load at atlas axis

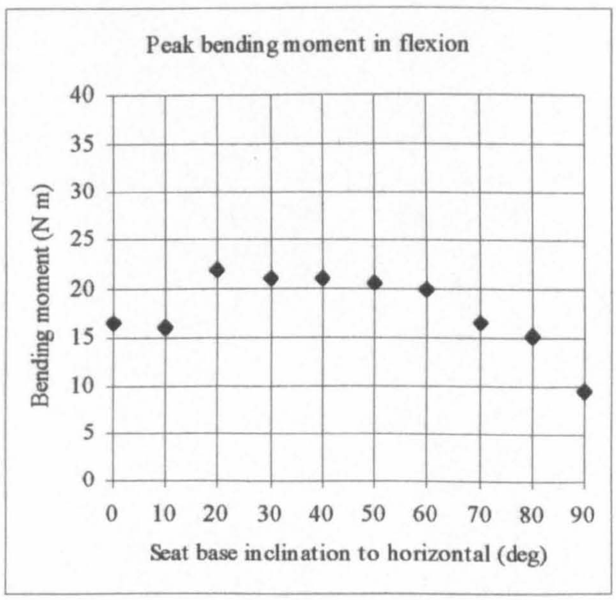


Figure 12.54 Peak bending moment at atlas axis

12.1.3. Seat Angle Evaluation Rear Facing Isofix 4 Point (Group 1 CRS) P3 Manikin

As previously stated some territories, Scandinavian countries in particular, favour the rear facing configuration of CRS for older children (Group 1) as well as infants, To support the design of such devices in combination with the Isofix interface, it was felt desirable to determine the optimal angle of CRS inclination to the horizontal from a performance point of view. A limited series of tests was conducted based on the pivoting 4 point Isofix CRS frame mounted rear facing. The TNO P3 manikin being of greater mass was selected for these tests as it was considered worst case with respect to mass/size.

Harness loads

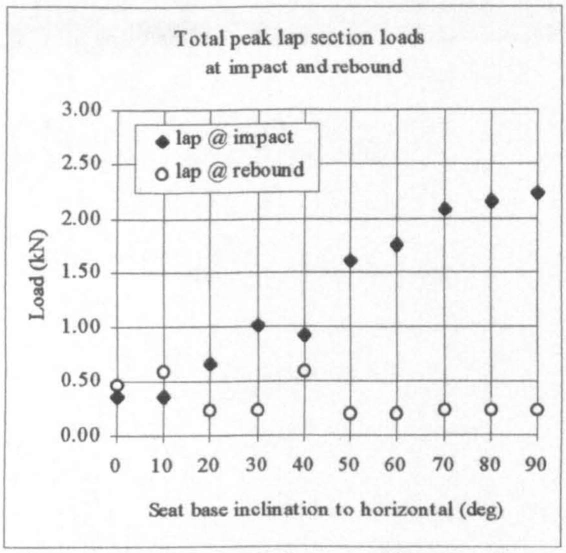


Figure 12.55 Peak lap section loads

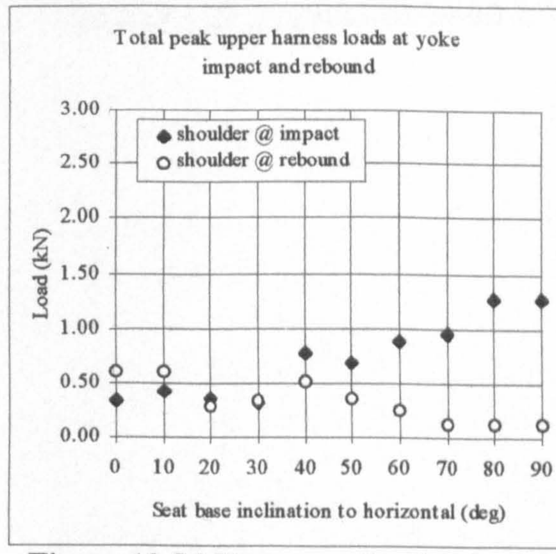


Figure 12.56 Upper section loads at harness yoke behind shell

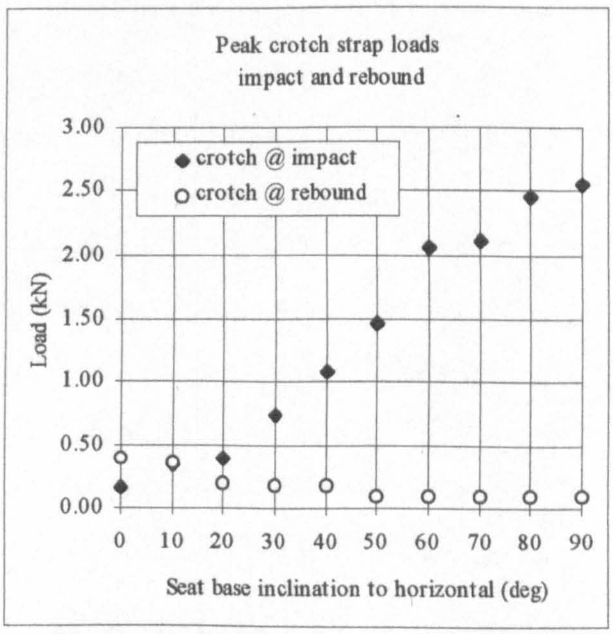


Figure 12.57 Peak crotch strap loads

The results shown above indicate that, as anticipated, with the seat back vertical, and base horizontal, peak harness loading during the impact phase of the event is minimal, the primary restraining medium being the seat shell.

Examination of the harness load data throughout the event indicated that in this upright condition the loading at impact is in fact less than that at rebound (indicating elastic deformation of the shell/frame, and/or the manikin). Once laid back from the upright position (head towards the direction of travel), the harness starts to play an increasing role in retarding the occupant, preventing the manikin from sliding up the seat back.

in retarding the occupant, preventing the manikin from sliding up the seat back. Interestingly it is the lap section and crotch strap that play the most prominent part in the harness system.

Resultant deceleration levels

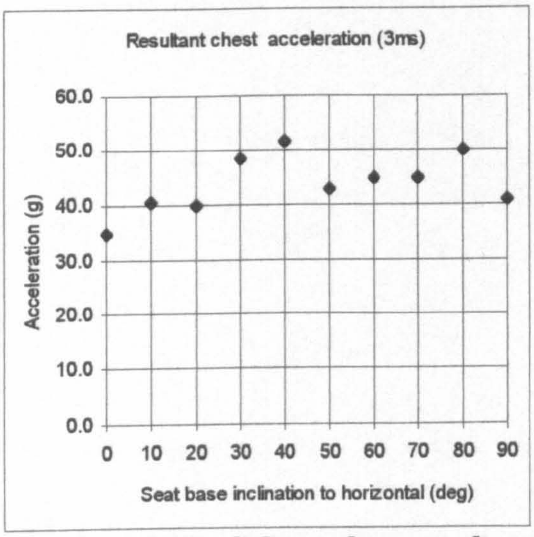


Figure 12.58 Peak 3 ms chest resultant

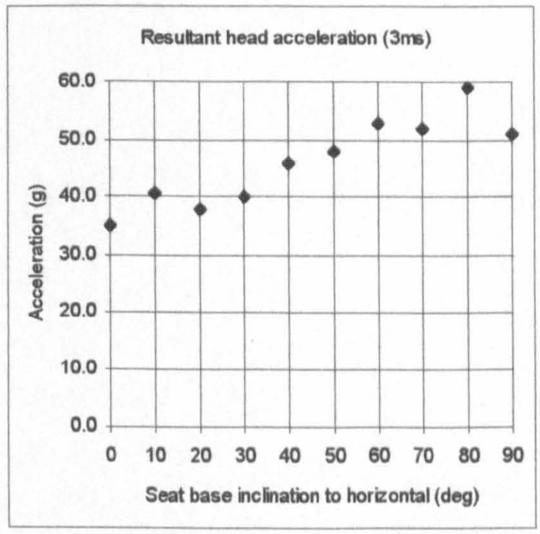


Figure 12.59 Peak 3 ms head resultant

When the deceleration traces for the manikin are reviewed, it is not surprising to find the chest and head resultant coincide when the seat is upright. In this configuration both the head and chest resultant are not unexpectedly comprised primarily of the 'x' component of the tri-axial accelerometers. In what may hence be considered an optimum practical situation for occupant deceleration the amplification factor defined as [peak occupant (chest) deceleration (35 g)/mean sled deceleration (14 g)] is only around 2.5. When the CRS inclination is increased and the harness starts to control to a greater extent the occupants coupling to the sled it can be see that both peak chest and head resultants increase to higher levels of 50/60 g. The level of chest resultant experienced on this rigid and hence fairly 'optimal' set up at an inclination of 40° is somewhat unexpectedly for a rear facing device approaching the R44 acceptance limit of 55 g. At the 40° inclination, the amplification factor in fact rises to 3.7. Figures 12.60 to 12.63 detail the peak output from the individual 'x' and 'z' chest accelerometers,

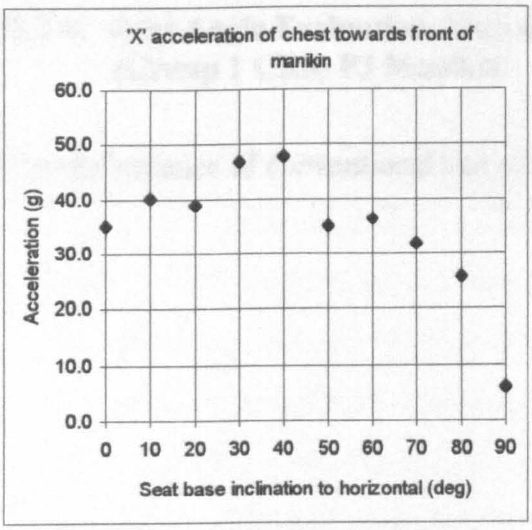


Figure 12.60 Peak chest 'x' accel on impact

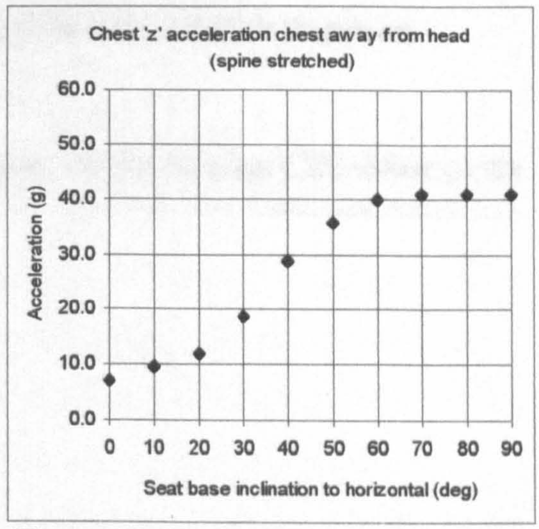


Figure 12.61 Peak chest 'z' accel on impact

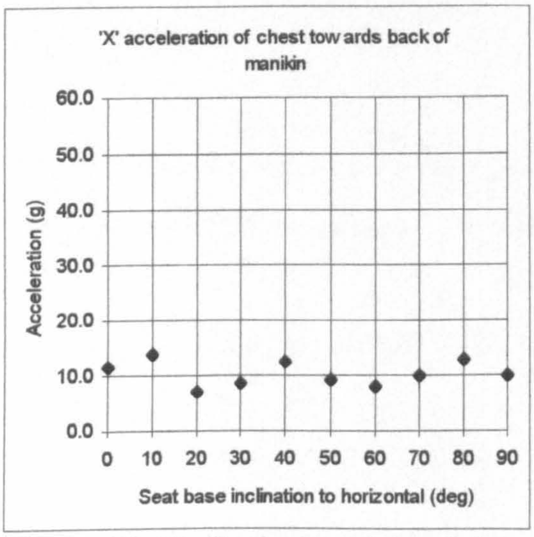


Figure 12.62 Peak chest 'x' accel on rebound

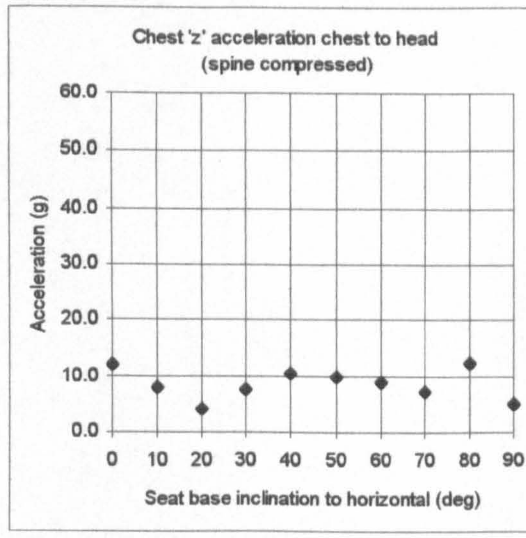


Figure 12.63 Peak chest 'z' accel on rebound

None of the above data would conflict with the acceptance requirements of R44, however the values of acceleration, chest away from head may require further investigation to determine if any detrimental effect would result.

Neck loading

Examination of the high speed video footage indicated neck motion to be insufficient to warrant re-testing in the limited time available with the neck load cell.

12.1.4. Seat Angle Evaluation, Forward facing Conventional Belt Retained (Group 1 CRS) P3 Manikin

The performance of conventional belt retained Group 1 forward facing CRS sitting on the test seat cushion to the ECE R44 standard has been described previously in this document. It has been noted that head excursion, arguably the most demanding parameter to achieve is a worst case in the CRS fully reclined configuration, where such a feature is offered. Further and not unsurprisingly retention of the CRS by only a static lap belt (commonly employed in the rear centre seating position) provides less rigid retention than if an automatic lap and diagonal adult belt were employed. This is because although the vital lap portion of the L&D belt is initially set at a slightly lower tension (50 N as opposed to 75 N), the diagonal will work as an asymmetric top tether (even with retractor spool out), limiting head excursion.

Hence the limited series of tests reported here were carried out on conventional CRS with increasing recline angle employed lap belt only retention.

To conduct the test a production steel framed CRS was suitably modified within the practical constraints of its design to offer seat base recline angles of between 30° and 60° degrees in 10° increments when installed upon the test seat cushion.

A P3 manikin was employed for all the tests, and all CRS set up parameters were as per the R44 requirements. Figures 12.64 and 12.65 detail the dynamic response of the described system.

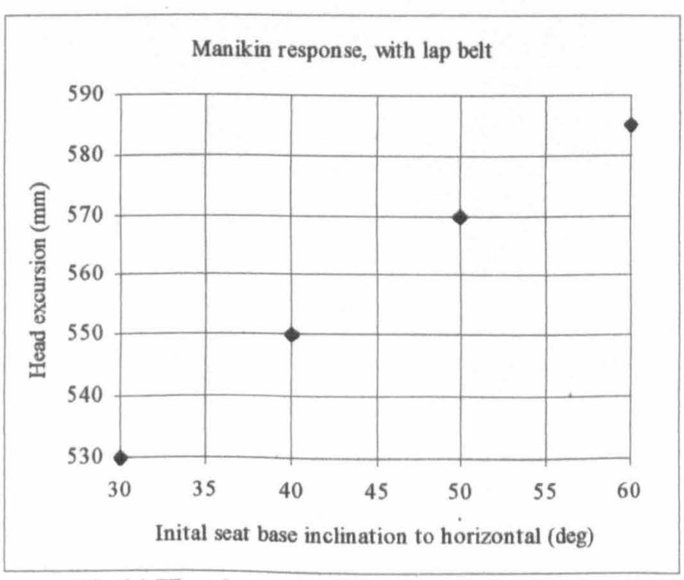


Figure 12.64 Head excursion, Lap belt retained CRS

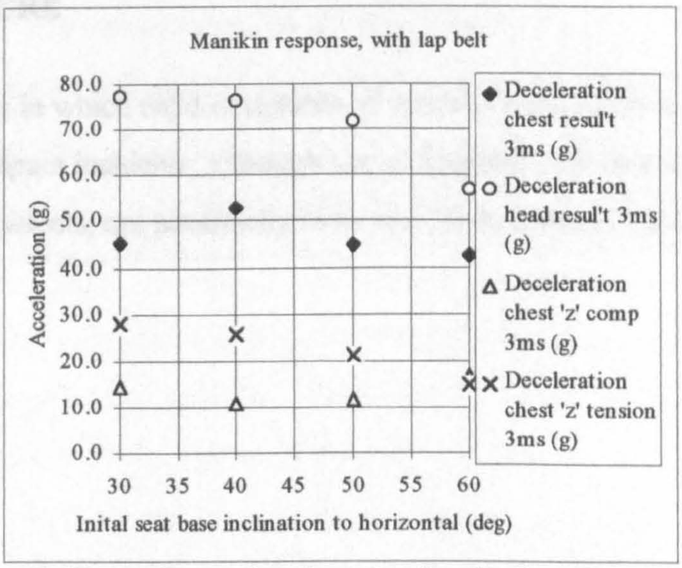


Figure 12.65 Resultant deceleration levels, Lap belt retention

It can be seen that although head excursion follows a similar trend to that observed with the rigid Isofix fixings, that is to increase with recline angle (over the range evaluated), resultant chest and head acceleration levels do not correspond accordingly. This it is felt is a result of the rotation of the CRS itself, further work is felt necessary to fully understand the process.

13. DEVELOPMENT OF AN IMPROVED SIDE IMPACT TEST PROCEDURE

Analysis of accidents in which child occupants of vehicles were killed or seriously injured indicates that side impact incidents, although not as frequent with respect to the total number of traffic accidents, are potentially more serious in terms of injury than the more common frontal/offset frontal incident, (Langwieder et al [11.10]). The adult belt retained CRS currently available in the UK are all approved to the European acceptance standard ECE R44 (03). Although comprehensive and exacting in most respects, ECE R44 03 does not incorporate a dynamic evaluation of CRS in a side impact. However it does specify minimal dimensions for energy absorbing material in the region of the occupant's head, and requires a head form drop-test to appraise the energy absorbing properties of the combined foam liner and seat shell.

The only countries currently conducting dynamic side impact tests of the CRS and attachment system are New Zealand and Australia [2.2][2.3]. These tests replicate a vehicle with a restrained child manikin, and are conducted on a conventional single sled. However as these tests ignore any intruding structure, they do not fully reflect the dynamic effects observed during actual lateral car-to-car impacts.

13.1. The side impact and child occupants

Due to the small number of lateral impact accidents involving restrained child occupants, Langwieder's [11.10] analysis was based upon world-wide accident data with disparate sample population sizes and sampling procedures. This data was used to highlight the increased risk to child occupants involved in lateral collisions. Of nearly 70000 accidents considered only 22.6% were lateral impacts, yet lateral impacts accounted for 34.5% of severe to fatal injuries (MAIS 3+) to restrained children (figure 13.1).

Sample	all impacts	lateral impacts	% lateral/all
Total car crashes	69,267	15,629	22.6
Children involved	8,004	1,475	18.4
Restrained children	3,948	673	17
MAIS 3+ restrained children (0-12y)	296	102	34.5

Figure 13.1 Distribution of severe/fatal injuries to restrained children with respect to impact [from 11.10]

To understand the impact types and injury mechanism involved a detailed study of comparative data from 10 institutes and covering restrained children sustaining MAIS 2+ injury [11.10]. These data indicate collision angle, impact velocity, seating position and deformation profile of the vehicle side structure each as a proportion of the relevant sample population (figures 13.2-13.5), and the distribution of injuries sustained by restrained child occupants in the lateral impacts (figure 13.6).

Angle (deg)	30°	60°	90°	120°
%	12	27	56	5

Figure 13.2 Collision angle [from 11.10]

vel (km/h)	<=30	<=50	<=80	>80
%	38	32	24	6

Figure 13.3 Impact velocity [from 11.10]

Seating position	Struck side	Centre	Non struck side
%	67	9	24

Figure 13.4 Seating position [from 11.10]

Type	Square shape	V shape	pole shape	other
%	49	39	10	2

Figure 13.5 Impact profile in vehicle side [from 11.10]

Body region	Head	Thorax	Abdo'n	Pelvis	C spine	T spine	L spine	Upper ext'y	Lower ext'y
% with AIS 2+	72	20	9	9	13	2	2	18	17
% with AIS 4+	40	10	-	-	11	-	-	-	-

Figure 13.6 Injury distribution [from 11.10]

These data show that critical injuries (AIS 4+) are most frequently sustained by the head, and identify the cervical spine and thorax the other particularly vulnerable areas.

The above data formed the basis for the test parameters to be replicated in a side impact sled test with intruding side structure. These are, an impact angle of between 60° and 90°, an impact velocity of up to 50 km/h and an intrusion profile of the side structure simulating a square or V shape.

13.2. Existing New Zealand Sled Based Side Impact Test

The New Zealand test procedure (outlined in chapter 8), conducted at 32 km/h entails rotating the test bench and CRS through 90° from its forward facing installation position (figure 13.7). CRS performance evaluation is based on deceleration levels and head excursion. See chapter 11.0 for evaluation of current (baseline) and proposed CRS concepts to the New Zealand side impact test procedure NZS 5411.

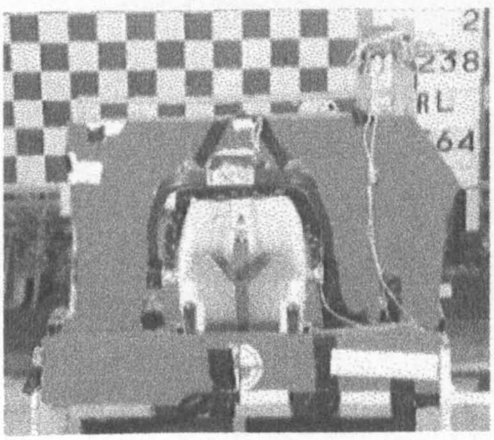


Figure 13.7 Sled set-up with rear facing infant carrier for New Zealand side impact test procedure NZS 5411 [2.2]

13.3 Side impacts in vehicles

The New Zealand test simulates a child occupying the centre or the non-struck side seating position. In these positions intrusion into the passenger compartment of the vehicle side structure during the initial phase of an impact does not present the same degree of hazard as for a child positioned in a struck side seating position. It is however important to prevent an occupant or manikin from subsequently impacting any intruded structure as the vehicle accelerates from under them. For the occupant of a CRS on the struck side of the vehicle, the centre line of the CRS will be, typically, in the order of 300 mm from the inner face of the vehicle door/side structure. During the initial phase of the impact the side structure will intrude rapidly reaching a velocity of equivalent to - even exceeding - that of the striking vehicle. The amount of intrusion into the passenger space may exceed 200 mm (Langwieder et al [11.10] suggests up to 400 mm) during a side impact concentrated at the centre of the vehicle, assuming two similar mid sized vehicles with an impact velocity of 50 km/h (figure 13.9).

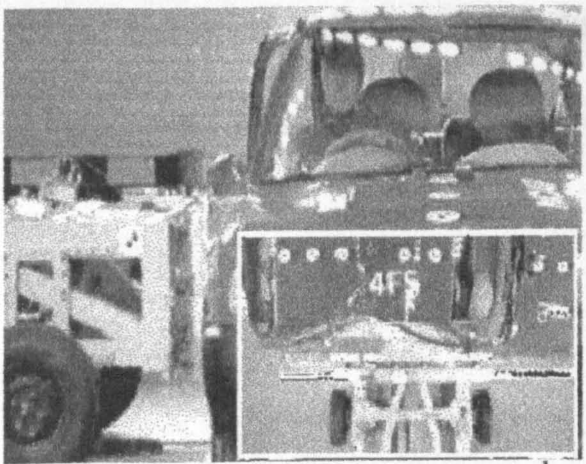


Figure 13.8 'B' pillar folding inwards [1]

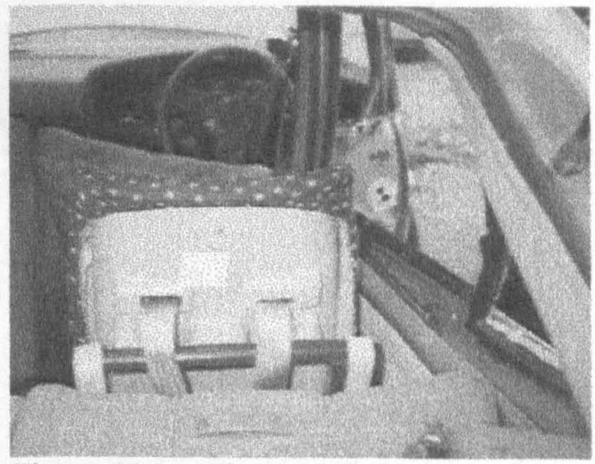


Figure 13.9 Plastic deformation of vehicle side structure[1]

With a four door vehicle, the centre side structure tends to fold in around the front door hinge and rear door rebate (figure 13.8) with the 'B' pillar and lower sill (rocker panel), if sufficiently high, absorbing the load.

Since the occupant on the struck side partly occupies the intrusion area prior to the impact the contact between intruding structure and CRS/occupant is likely to be violent. With a forward facing CRS it is likely to be the leg that is struck by the intruding structure during the initial phase. For a rear facing infant carrier on the rear struck side it is the head/shoulder area that will initially contact the intruding structure. During the later phase of the event, the occupant will remain in contact with the intruded structure as the vehicle moves from underneath. Since current CRS in Europe are predominately retained by adult lap, or lap and diagonal belts, these have a less well laterally restrained upper section. It is, therefore, the head/upper body of a child in a forward facing CRS that tends to contact the side structure. There is also a case for evaluating CRS in the centre or non struck side seat position; occupants may avoid the initial intrusion phase but may suffer injury from the later phase.

The objective of the work described in this section was to ascertain the practicability of developing a simple and reproducible side impact sled test with intruding side structure representative of typical vehicle to vehicle side impact at 50 km/h for possible incorporation in an international standard. The aim was to develop a test compatible with a single sled of the type used widely for CRS evaluation and certification purposes in Europe (Appendix 7).

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[1] Photograph courtesy of TRL

13.3.1. Full Scale Vehicle Testing at TRL

To establish the parameters for a side impact sled test, the results of full scale vehicle crash tests conducted by Transport Research Laboratory (TRL) were analysed to provide both vehicle and occupant response data. The vehicles employed were late 1980's mid sized 4 door family saloons without sophisticated side impact protection systems.

With a restrained TNO P3 manikin, with both head and chest tri-axial accelerometers, the seating position was varied from struck side rear to centre rear. To record acceleration in the lateral (across car) direction the CRS was fitted with an additional single axis accelerometer on its frame at a point as near to the centre of mass as possible. The vehicles were fitted with accelerometers in the area of the non struck 'B' pillar and on a cross car acceleration tube fitted just ahead of the manikin in the rear of the vehicle. The cross car acceleration tube enabled calculation of acceleration of the side structure as it deformed inwards and, by means of a tell-tail, assessment of maximum deformation. Figure 13.10 shows the cross car acceleration tube in position just ahead of the manikin's chest/abdomen. The larger diameter portion of the tube located between the struck door and the single axis accelerometer incorporates a damping medium to minimise 'ringing' that would otherwise affect the accelerometer response as the door is impacted. The data acquisition techniques employed during the analysis were as defined in the R44 frontal impact requirements.

Figure 13.10 Struck side child occupant prior to impact, conventional CRS[1]

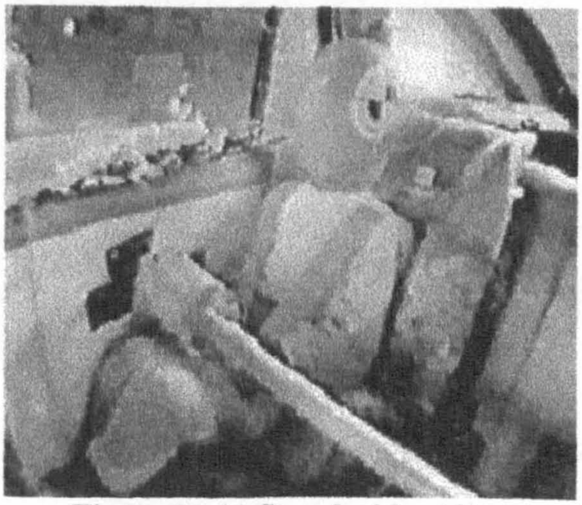

Figure 13.11 Struck side child occupant at maximum intrusion, conventional CRS[1]

[1] Photograph courtesy of TRL

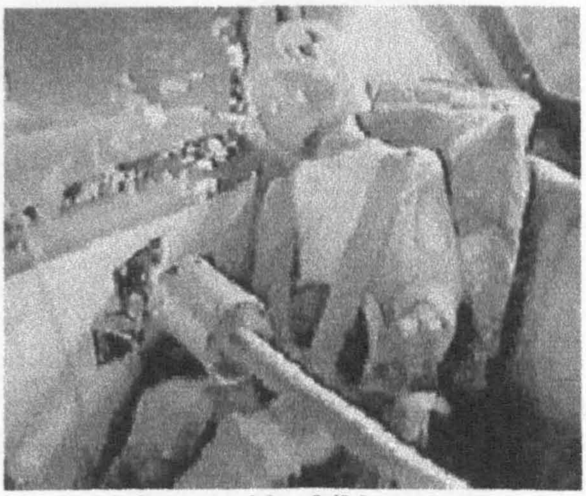

Figure 13.12 Struck side child occupant as target vehicle accelerates, conventional CRS[1]

Figure 13.11 shows a struck side occupant at the point of maximum intrusion of the side structure. At this point in the impact the only contact with the occupant is with the lower extremities. The head and upper torso will contact the structure some 30 ms later as the vehicle accelerates from below (figure 13.12).

Figures 13.13 and 13.14 show a centre positioned conventional CRS at maximum intrusion, when the vehicle accelerates from underneath the CRS. There was no contact between the side structure and occupant during the intrusion phase. In this centre seat position the occupant's head will still impact the door top if in a less well retained CRS.

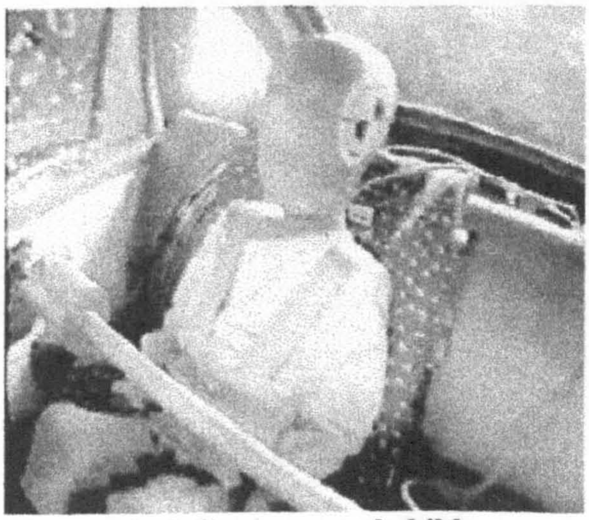

Figure 13.13 Centre seated child occupant at maximum intrusion, conventional CRS[1]

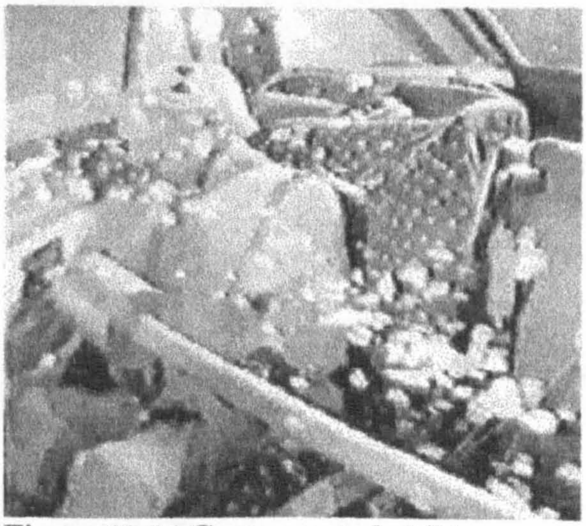

Figure 13.14 Centre seated child occupant as target vehicle accelerates, conventional CRS[1]

[1] Photograph courtesy of TRL

The following sections describe the dynamic response of both vehicle and occupant in the struck side and centre seat position impacts.

•

13.3.2. Analysis of Vehicle Test Data

The data are divided into vehicle kinematics and CRS/occupant response. The former was used to develop equipment used in the sled test to replicate the input to the CRS, and the CRS/manikin output data used to compare the vehicle/sled manikin response for validation purposes.

13.3.2.1. Dynamic Response of Struck Vehicle

Six full scale vehicle tests were conducted in total at TRL with different CRS/seating position combinations at impact velocities of 50 km/h (13.89 m/s). The vehicle response data for all six tests [13.1] were used to decide typical response envelopes to which the vehicle tests conformed. The basic sled test parameters based on intrusion velocity and struck vehicle acceleration were required to be within these envelopes.

Figure 13.15 details the angular velocity of a hinged plane representing the vehicle side structure intrusion calculated from the full scale impact tests. In addition figure 13.16 details the lateral acceleration of the struck (initially stationary) target vehicle as it accelerates up to approximately 50% of the striking trolley velocity. The mass of the vehicle and trolley being similar.

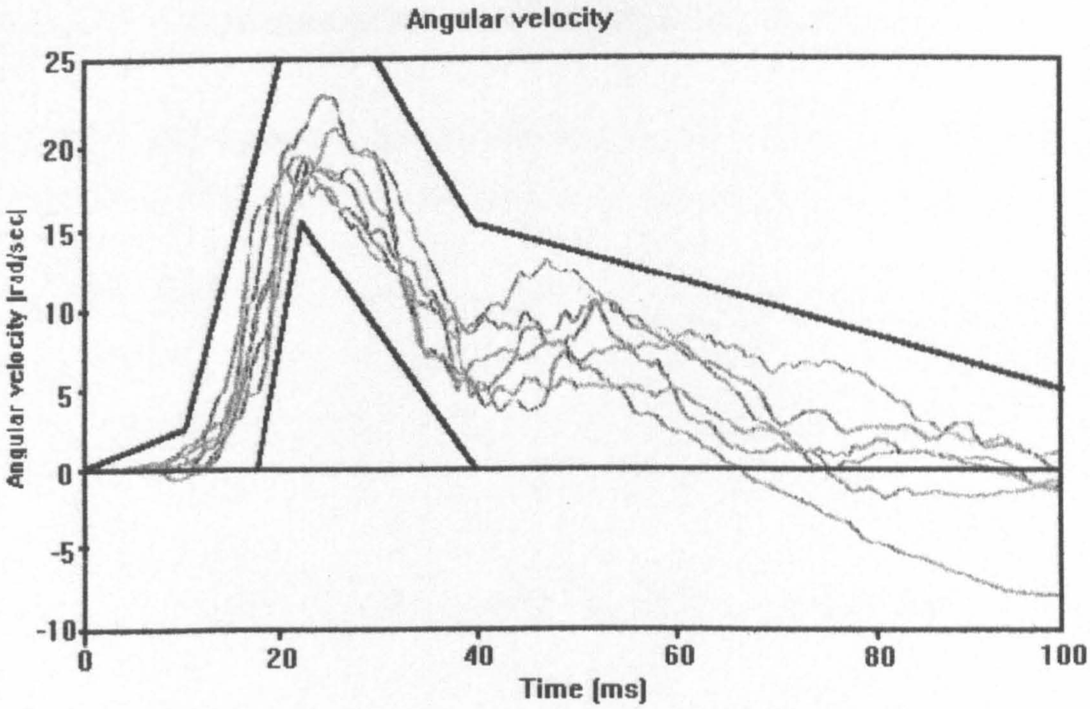

Figure 13.15 Angular velocity of vehicle side structure with respect to vehicle frame of reference [13.1]

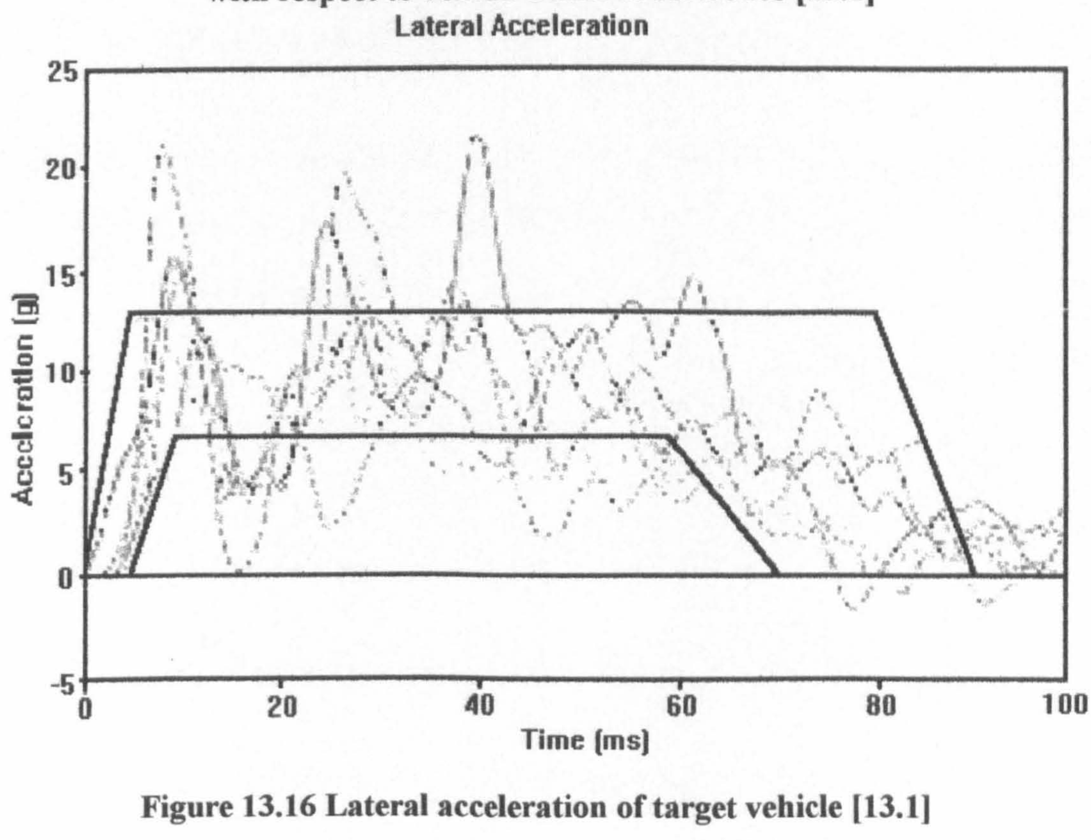

Figure 13.16 Lateral acceleration of target vehicle [13.1]

13.3.2.2. Occupant response in vehicle tests [11.10][13.1]

The following sections detail the response of the TNO P3 manikin restrained in both conventional and prototype Isofix CRS.

13.3.2.2.1. Conventional Belt Retained CRS/Occupant Response

The CRS and manikin response accelerations obtained from conventional (ECE R44 02) CRS in the struck side and centre seat positions are as detailed in figure 3.17.

Test	Peak CRS acceleration (g)	Chest resultant acceleration 3 ms [Peak] (g)	Head resultant acceleration 3 ms [Peak] (g)
Struck side seating position	118	56 [67]	42 [45]
Centre seating position	38	[39]	[137]

Figure 13.17 Conventional CRS and manikin response

13.3.2.2.2. Rigidly Attached CRS and Occupant Response

The CRS and manikin response accelerations obtained from the rigidly attached CRS 4 point Isofix (the preferred Isofix concept at the time) in the struck side and centre seat positions are as detailed in figure 3.18.

Test	Peak CRS acceleration (g)	Chest resultant acceleration [Peak] (g)	Head resultant acceleration [Peak] (g)
Struck side seating position	50	[77]	[38.5]
Centre seating position	21	[24]	[24]

Figure 13.18 Rigidly attached CRS and manikin response

It is important to note the improved occupant response levels obtained from the rigidly attached CRS compared with conventional CRS, particularly in the centre seat positioned CRS. The importance of restraining the manikin within the protective side wings of the CRS should also be recognised to minimise direct contacts with the manikin.

13.4. Simulating a Side Impact Collision.

Compared with frontal impacts a sled based side impact test with intruding structure is complex. The test is complicated by the interaction between vehicle shell, CRS, occupant and intruding structure both in terms of accelerations/load input levels and, just as critically, the timing of events.

To simulate the events observed in the full scale vehicle tests it is necessary to locate the manikin adjacent to structures of similar mass and stiffness to that of the vehicle (both are difficult to define). With the manikin suitably positioned/restrained the intruding side structure is accelerated towards the centre of the 'vehicle' to reach a velocity equivalent to that of the striking vehicle (e.g. 50 km/h) then decelerated again. This must be achieved within the total deformation observed (including the elastic element) of the side structure in an actual vehicle. Simultaneously, the test seat (bench) must be accelerated from under the manikin until it reaches the common velocity of both vehicles at impact. Assuming the conservation of energy and vehicles of similar mass this would be approximately 25 km/h.

Figure 13.19 shows typical linear velocities of the striking/struck vehicle shells and the velocity of the side structure of the struck vehicle with a vehicle to vehicle perpendicular distributed side impact at 50 km/h.

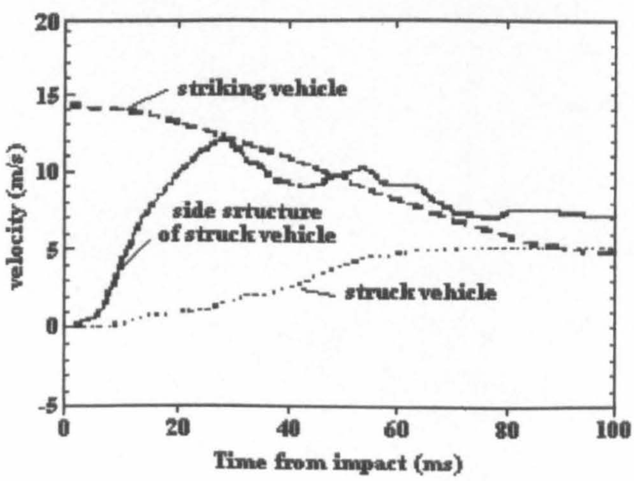

Figure 13.19 Typical velocities of struck and striking vehicles

To achieve repeatability of these simulated events on a deceleration sled is difficult. In figure 13.19 it is assumed that the target vehicle and occupant are initially stationary with respect to ground at impact. For a deceleration type sled pulse to represent the acceleration of the vehicle shell, the sled and occupant must decelerate from 25 km/h with respect to the ground. Simultaneously the representative intruding structure must be accelerated, to approximately 50 km/h, with respect to the occupant. The intruding structure if attached to the sled (which it must be because of the different sled stopping distance) must also decelerate from 25 km/h before being accelerated in the opposite direction up to approximately 25 km/h with respect to the ground. This deceleration and subsequent acceleration (relative to the ground) of the intruding structure must take place during the initial sled deceleration phase. It is evident from figure 13.19 that the intruding structure attains the velocity of the striking vehicle within 30 ms of impact when the shell of the struck vehicle has only reached a velocity of approx 1.5 m/s (of a maximum 6-7 m/s). A deceleration sled is not ideal for simulating these events. To achieve the required deceleration pulse with a delta V of 25 km/h requires a sled stopping distance of approximately 400 mm, whilst the intruding structure only travels approximately 200 mm (as observed in the TRL vehicle tests) at the beginning of the sled deceleration pulse. If a stationary impactor were used to actuate the intruding structure subsequent motion of the sled would sever the intruding structure off the sled, if the impactor were not moved away. Another major disadvantage of the deceleration sled is that it is difficult to achieve the required velocity of the intruding structure relative to the occupant. To stop the intruding structure with a fixed impactor results in a peak velocity change of 25 km/h. However a 50 km/h velocity change with respect to the occupant must be achieved, hence either a spring/leaver mechanism or a combination of the two is necessary.

13.4.1. Development of Sled Set Up for Intruding Structure Side Impact Test

The sled set up was similar to that employed for the existing New Zealand side impact test with the test seat bench and its associated 'C' pillar mounted longitudinally (representing a rear seat configuration). It was necessary to modify the front of the sled to mount an intruding panel. The panel was hinged - at a position relative to the test bench - that represented the rear door rebate of a vehicle in the area of the door latch. The hinge line of the intrusion panel was perpendicular to the surface of the test bench cushion to prevent contact between the panel and test bench. The intrusion panel dimensions were similar to the lower half of a vehicle rear door with a mass (37 kg) intended initially to represent a vehicle door with some additional surrounding structure. Figures 13.20 and 13.21 show a schematic and picture of the initial set-up.

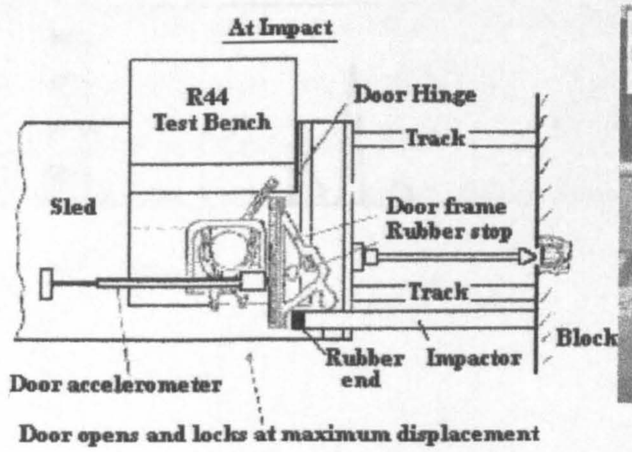

Figure 13.20 Plan view of set-up on sled

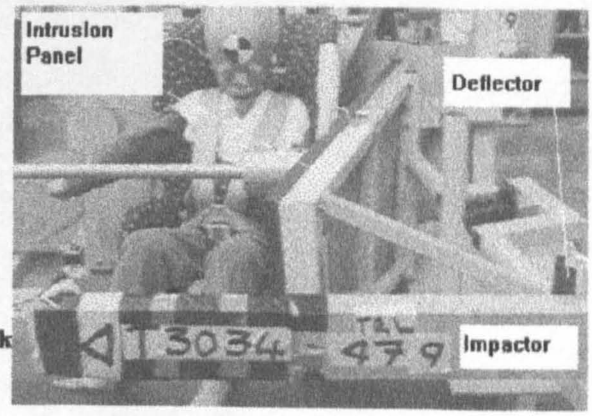

Figure 13.21 Front view of set-up on sled

The design of the impact panel allowed the impactor, attached to the 'head block' of the sled, to disengage when the full travel of the panel had been reached. The impactor was positioned on the outside edge of the panel - the only feasible location - and was tipped with a stiff (rubber) spring to increase the panel outer edge velocity as it left the impactor. With this arrangement, however, the maximum velocity of the panel was no greater than the sled impact velocity as the impactor after decelerating the outer edge of the panel remained in contact during the sled deceleration phase (this was attributed to losses). This being the case the angular velocity of the impact panel could only reach the desired level observed in the vehicle tests if the sled impact velocity were increased above 25 km/h. By reducing the mass of the intrusion panel to only 13 kg it was possible to increase the angular velocity to approach those in the vehicle tests. Figure 13.22 shows this configuration with the CRS and manikin removed (post test), whilst figures 13.23, 13.24 and 13.25 detail the panel response.

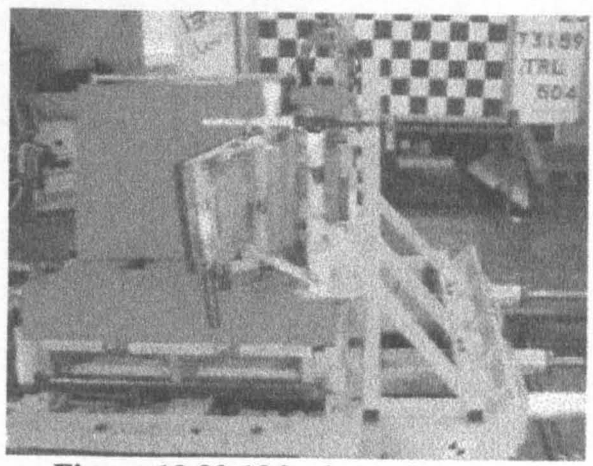

Figure 13.22 13 kg intrusion panel

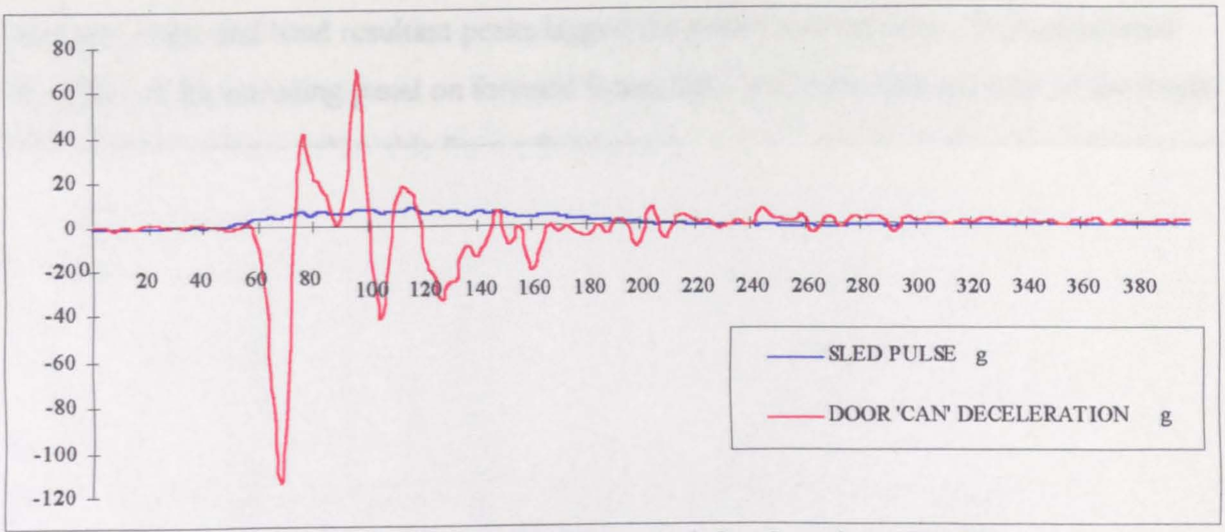

Figure 13.23 Sled and 13 kg panel deceleration (T3159)

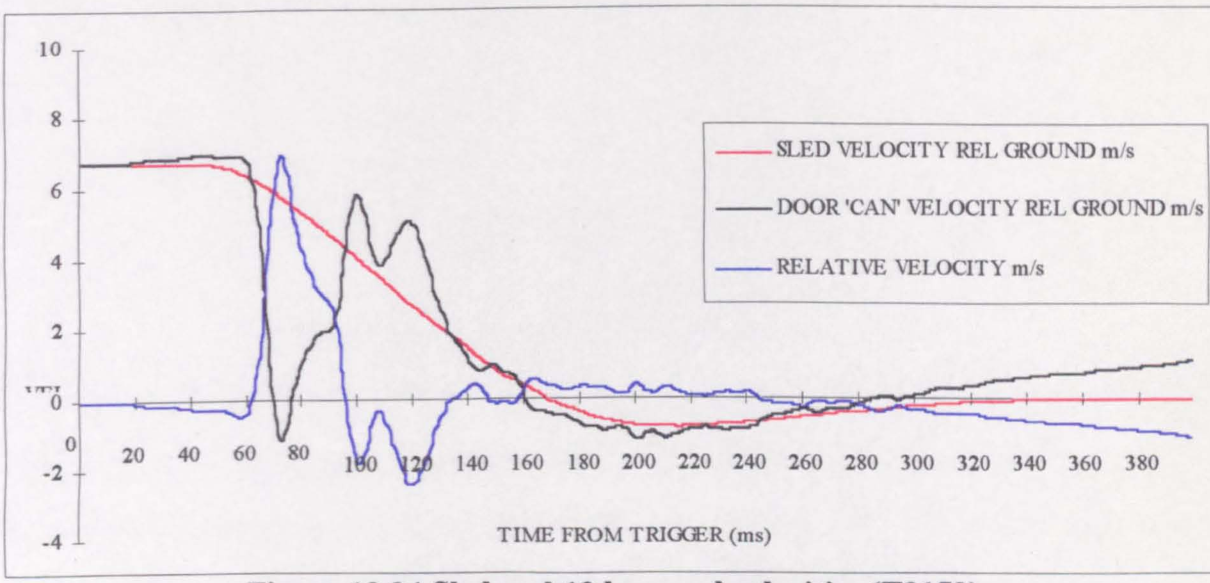

Figure 13.24 Sled and 13 kg panel velocities (T3159)

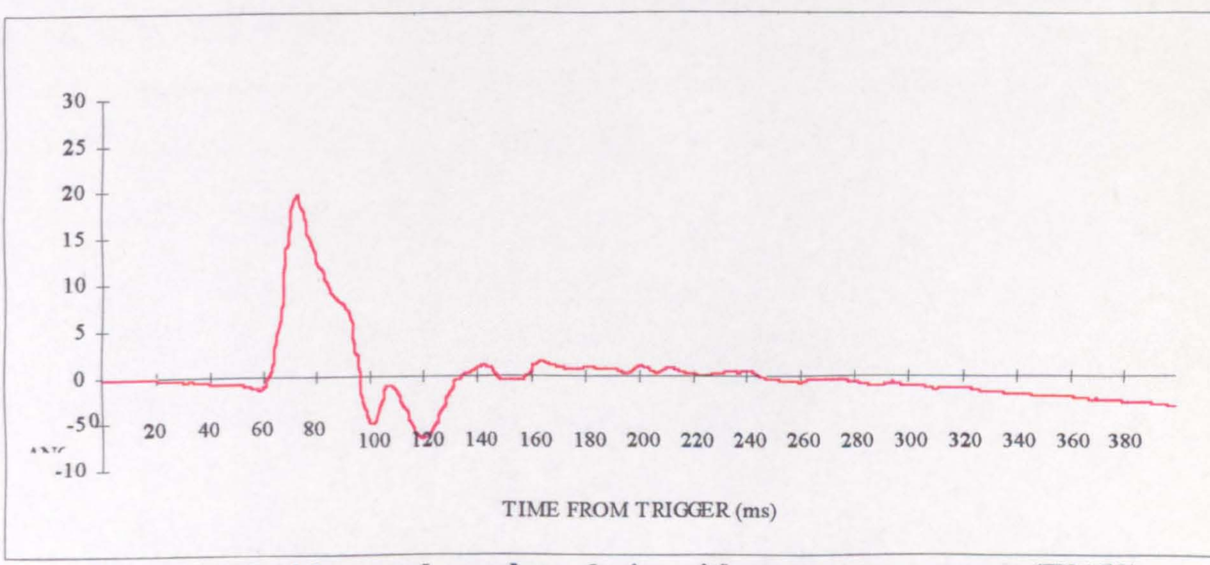

Figure 13.25 13 kg panel angular velocity with respect to occupant (T3159)

Although the desired peak angular velocity for the intruding structure was approached, occupant response levels (Figure 13.26) were below those in the vehicle tests. Further, the occupant chest and head resultant peaks lagged the peak panel velocity. This questioned the effect of the intruding panel on forward facing CRS and raised the question of the levels of occupant response achievable from a fixed panel.

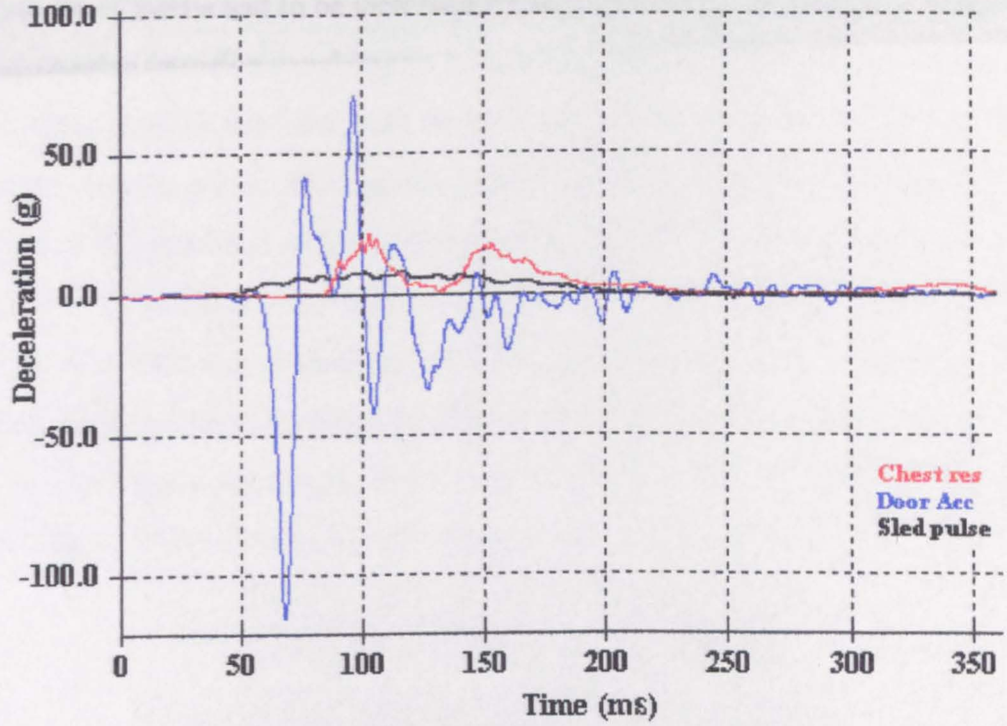

Figure 13.26 Occupant response in test (T3159)

13.4.1.1 Fixed intrusion panel

Figure 13.27 details the response from a subsequent test with a fixed intruded panel. Whilst the head response was of the right order, the chest was low. This would imply that impact of the lower torso with an intruding panel of sufficient mass may indeed contribute to the occupant response.

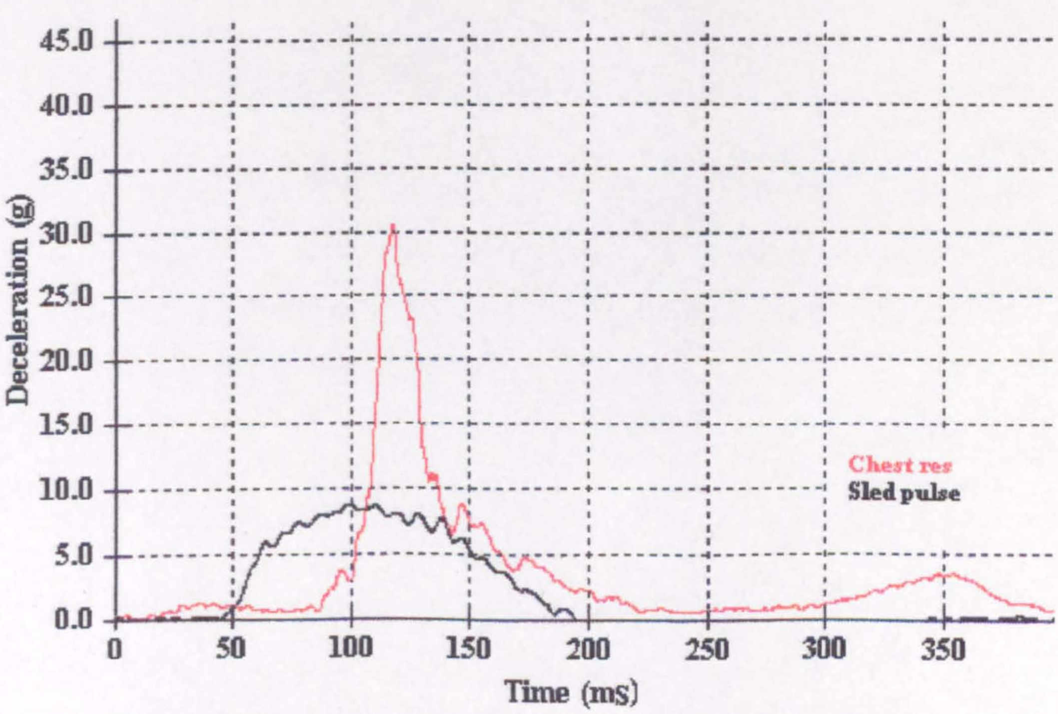

Figure 13.27 Occupant response in fixed panel test (T3337)

13.4.1.2 Sled test with intruding side structure

To devise a test with an occupant response approaching that in the vehicle tests, the panel mass/moment of inertia had to be increased whilst maintaining panel angular velocity. For this an alternative intrusion panel impactor regime was employed. Instead of being fixed to the head of the sled the impactor, with its stiff rubber spring at its tip, was free to 'fly clear' after impact with the panel. This had the benefit of allowing the impactor to strike the centre area of the panel and an increase in angular velocity. By striking nearer the point of percussion it was possible to increase the angular velocity of the panel without overloading the hinges. The following preliminary calculations were supported by subsequent mathematical modelling to establish the characteristics of the spring and panel/impactor masses and the impact point required to realise the desired panel acceleration/angular velocity. Figure 13.28 shows the final intruding panel side impact test configuration.

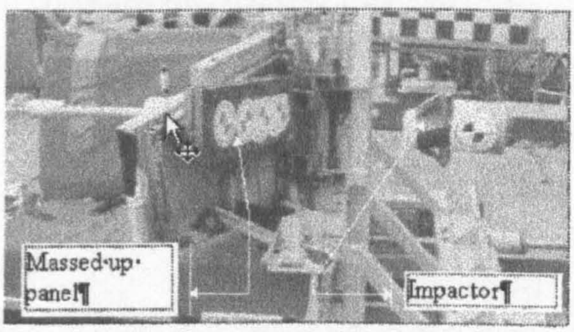

Figure 13.28 Final intruding panel side impact test configuration

Initial calculations were based on a test 'Intruding Panel' with mass (M_D) increased to 30 kg.

<u>Moment of Inertia of 'intrusion panel' + latch</u>

Due to the complex nature of the 'intrusion panel', calculations of its moment of inertia about the hinge (I_O) and location of the centre of mass (h) with respect to the hinge were based upon empirical observations, by swinging it about its hinge to find its period and by suspension to evaluate the position of the centre of mass.

Using the expression $T = 2x\pi \sqrt{(I_O / M_d x g x h)}$ **Equation 2**

It can be shown that $\mathbf{I_O = 3.92\ kgm^2}$

$h = 0.328$ m

<u>Point of percussion of the 'intrusion panel' (assumes rectangular panel)</u>

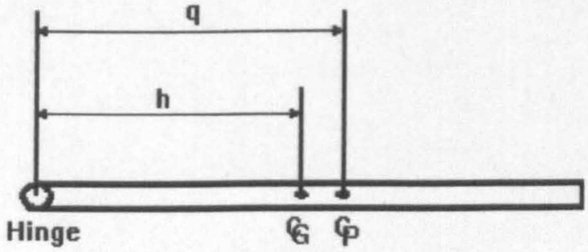

Figure 13.29

To minimise the load on the hinge, it is necessary to strike the 'intrusion panel' at the centre of percussion (C of P), at this point $\sum$moments about it = 0.

The distance from the hinge to C of P (q) = K_O^2/h **Equation 3**

Where K_O is the radius of gyration about hinge

$K_O = \sqrt{(I_O/M_D)}$

$K_O = \sqrt{(3.92/30)}$

$K_O = 0.36$ m

$h = 0.328$ m

Hence $q = 0.361^2/0.328$

q = 0.397 m

The resulting C of P would appear may lie beyond the C of G. Although the C of P point gives the minimum loading on the hinge, it does not necessarily represent the impact point for peak angular acceleration and hence the angular velocity of the 'intrusion panel'. The following analysis attempts to predict both the optimum impact point and associated impact mass (within practical constraints) for peak velocity of the intrusion panel as it leaves the rubber tipped impactor. It is necessary to optimise the angular velocity as this is a factor in the force to be imparted to the CRS and, hence, the occupant.

Angular velocity of struck 'intrusion panel'

The peak angular velocity of the struck 'intrusion panel' (ω) depends upon a number of factors:-

The mass of the impactor (M_I) = 10-100 kg

Relative impact velocity (ΔV) = 6.94 m/s

Distance from hinge to C of G (h) = 0.328 m

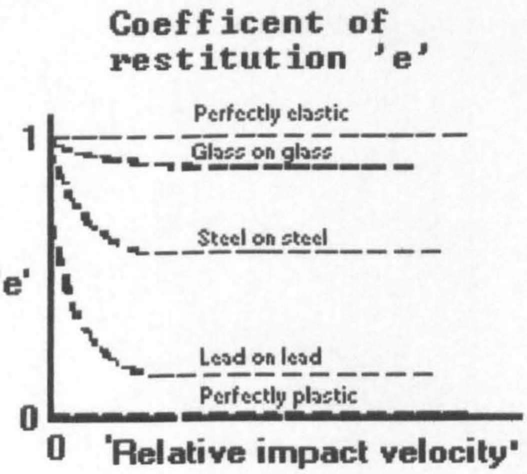

Figure 13.30 Coefficient of restitution taken from [13.2[

Coefficient of restitution (e)

'ratio of the relative separation velocity to the relative approach velocity measured along the direction of contact forces'

Taken as

$e = 0.2$

for first estimate

Moment of inertia about hinge(I_O) $= 3.92 \text{ kgm}^2$

A prediction for angular velocity was obtained (after Bedford and Fowler [13.2]) based on the conservation of angular momentum
and assuming the test panel to be a slim rectangular section with vertical hinge.

Angular velocity ω $= [M_I x \Delta V x h x (1+e)]/[I_{Ohinge}+(M_I x h^2)]$ **Equation 4**

Figure 13.31 indicates the predicted increase in angular velocity with respect to impact distance from hinge for an increasing impactor mass from 10 kg to 100 kg. It also shows that the heavier impactor should strike the 'intrusion panel' closer to the hinge than the approximated ideal centre of percussion.

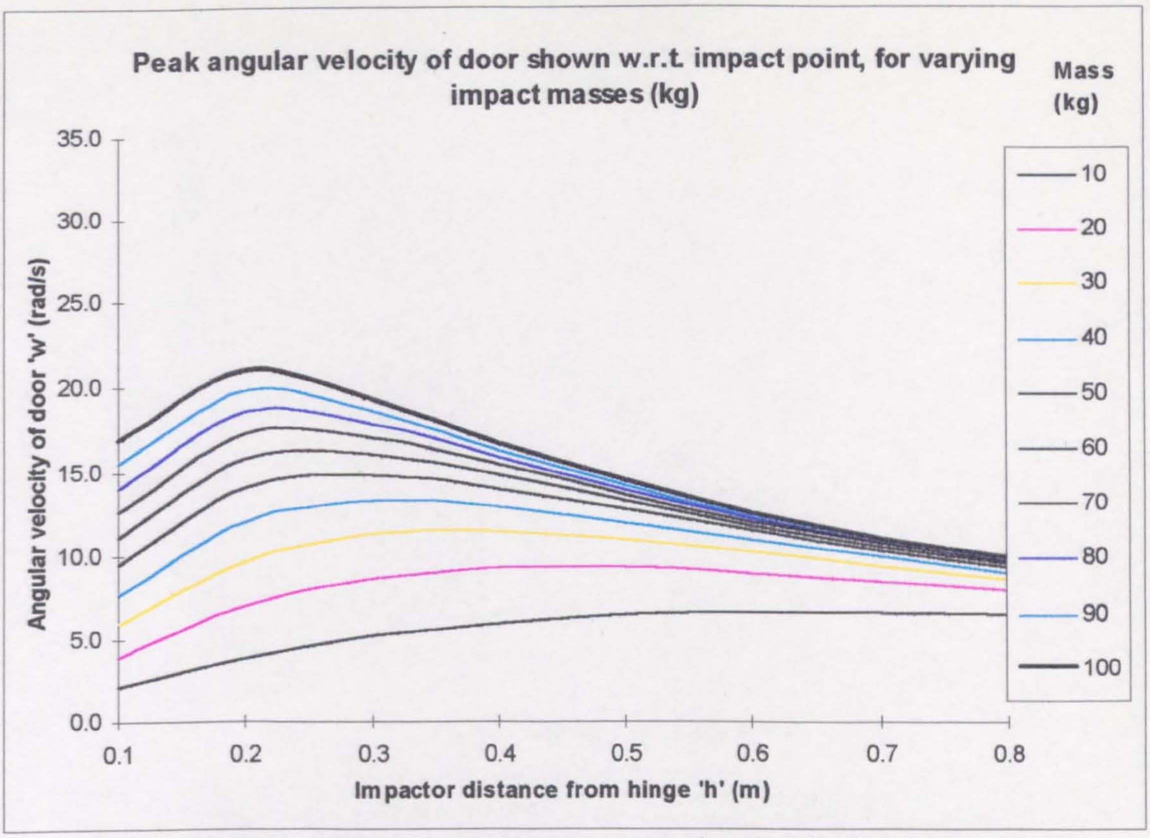

Figure 13.31 Predicted 'intruding structure' velocities for 30 kg panel

The point of impact (distance h from hinge) for peak angular velocity occurs when $(d\omega/dh)$ is zero

$$\omega = [M_I x \Delta V x h x (1+e)]/[I_O+(M_I x h^2)] \quad \textbf{Equation 5}$$

As all except ω and h are constant in a given set-up

$$\text{let } k = M_I x \Delta V x(1+e),\ c = I_O,\ d = M_I$$

$$\omega = kh / c + dh^2 = kh \times (c + dh^2)^{-1}$$

differentiating gives. $$(d\omega/dh) = [k / (c + dh^2)]-[k2dh^2 / (c + dh^2)^2]$$

when $(d\omega/dh) = 0$ $$0 = [k / (c + dh^2)]-[k2dh^2 / (c + dh^2)^2]$$

$$\therefore \quad k / (c + dh^2) = k2dh^2 / (c + dh^2)^2$$

$$\therefore \quad h^2 = c/d$$

$$\therefore \quad h = \sqrt{(c/d)}$$

$$\therefore \quad h = \sqrt{(I_O / M_I)}$$

Given the above value of I_O (i.e. 3.92 kgm^2) and peak value of M_I practicable (i.e. 100 kg)

$$\therefore \quad h = \sqrt{(3.92 / 100)} \qquad 0.198 \text{ m from hinge}$$

Figure 13.32 represents the actual angular velocities of the 30 kg 'intrusion panel' when assessed on the test rig set up without a CRS or manikin, the panel being struck at between 200 mm and 500 mm from the hinge with the 100 kg impactor.

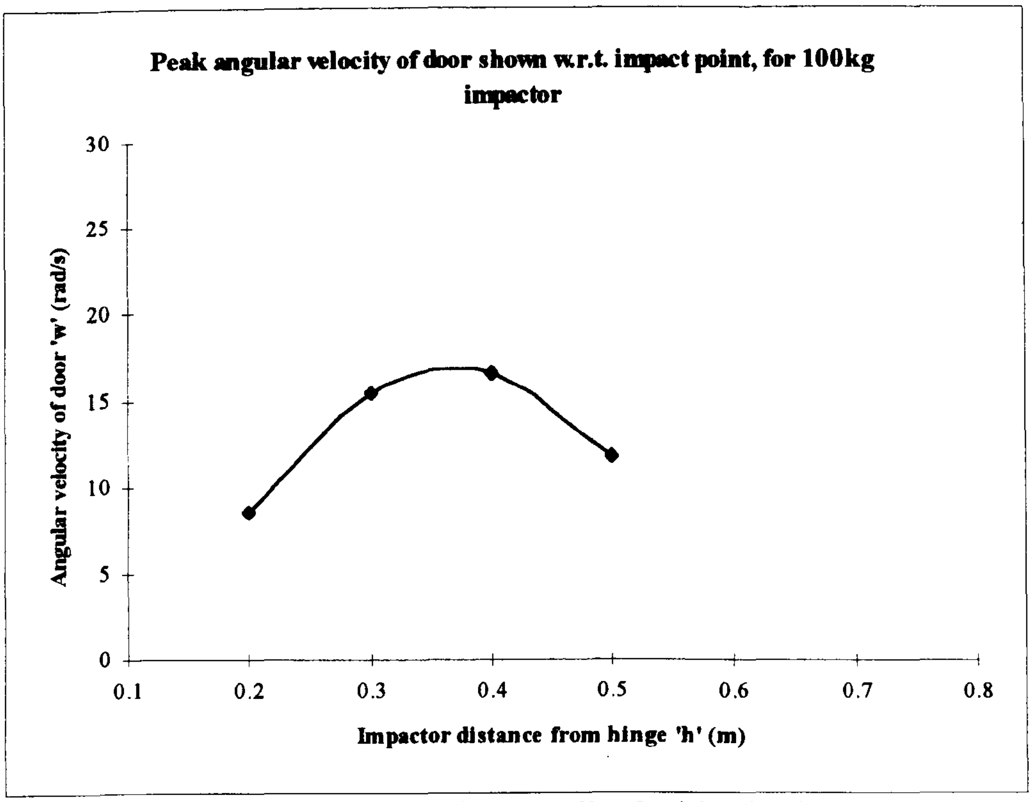

Figure 13.32 Actual 'intrusion panel' velocities for 30 kg panel

Figure 13.32 indicates the predictions are slightly optimistic, the peak values of 'ω' being found in the dynamic tests to be some 21% below the calculated figure. In addition the 'h' distance from the hinge at which peak velocity was predicted appears to be about 370 mm, almost twice the predicted 198 mm.

The assumptions included an estimated value of 'e' (coefficient of restitution). However the value of 'e', although considered constant in classical theory, has more recently been shown to be highly dependent upon geometry and impact velocity and has been described as a complex and variable factor [13.3]. This assumed value may therefore warrant further examination. The increased 'h' value evident in the dynamic tests still remains unexplained but it must be remembered that the theoretical calculations were based upon slim rectangular section with vertical hinge. This was not the case in reality, the intrusion panel was 50 mm thick, with hinges which were inclined 17° from the vertical.

Final development test

Test 3525 describes the final specification level for the test. The intrusion panel had a mass of 30 kg, with an $I_{hinge} = 3.92$ kgm^2. The impactor mass was 100 kg with a rubber impact end (70° hardness, ∅80 mm x length 100 mm). The test CRS and manikin were as in the initial vehicle tests, whilst the panel inner surface was skinned with a polyurethane rubber 25 mm thick, identical to the TNO manikin skin.

Figure 13.33 describes the input data in terms of linear velocity during the impact. Impact velocity will be observed as 7.02 m/s (target 6.94 m/s) although as with all tests on deceleration sleds of this type employing polyurethane deceleration tubes, the actual ΔV of the sled is slightly greater due to sled rebound (7.65 m/s).

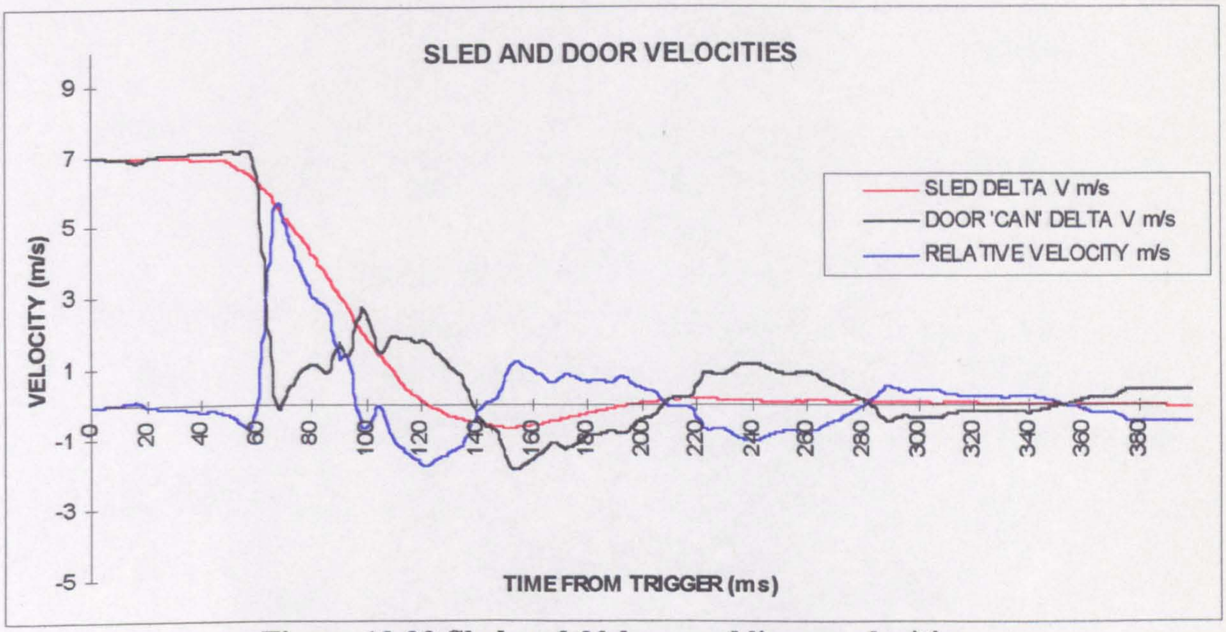

Figure 13.33 Sled and 30 kg panel linear velocities

Figures 13.34 and 13.35 detail the angular intrusion panel velocity achieved and the linear deceleration of the sled.

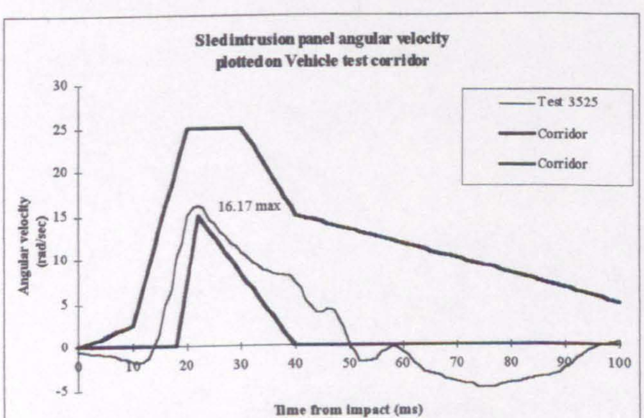

Figure 13.34 Angular panel velocity

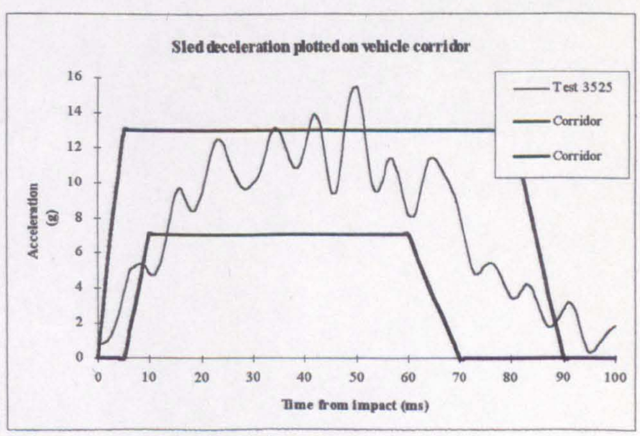

Figure 13.35 Sled deceleration

Figure 13.36 details the occupant response obtained during this test and the results shown in comparison with the full scale vehicle tests in figure 13.37.

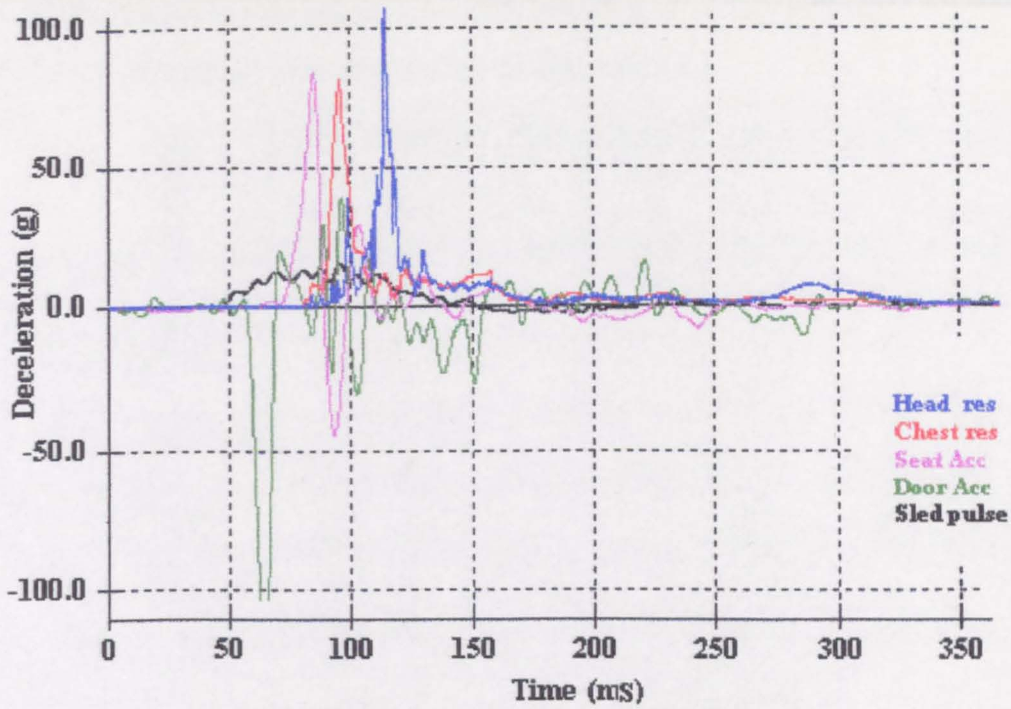

Figure 13.36 Manikin response T3525

Test	Resultant 3 ms chest acceleration [peak accel] (g)	Resultant 3 ms head acceleration [peak accel] (g)	Lateral CRS acceleration (g)
Full scale vehicle test	56 [67]	42 [45]	118
Test 3525	66 [82]	61 [107]	85

Figure 13.37 Manikin response in comparative tests

It can be seen that although the peak lateral acceleration of the CRS was observed to be low compared with that in the vehicle tests (lower intrusion panel velocity), the chest response in the sled test is similar to that in the vehicle test whilst the head response is significantly higher. The higher head resultant may be attributed to the very stiff nature of the head contact zone on the intrusion panel. In terms of both height and stiffness this requires further development.

13.5 Sled tests of current and proposed CRS types

Although the developed intruding structure sled test does not fully reflect the baseline vehicle tests used, testing of CRS (conventional and prototype Isofix) was conducted to enable some comparisons to be made with the New Zealand side impact test. It should be noted that the developed sled test velocity change was slightly lower than that of NZS 5411.

Figure 13.38 compares side impact tests with intruding structure with tests conducted to the New Zealand side impact procedures without side structure.

	New Zealand test (8.9 m/s impact)				Intrusion panel test (6.9 m/s impact)			
	Test No	Chest resultant	Head resultant	Planer head excursion	Test No	Chest resultant	Head resultant	CRS lateral accel
CRS type		g	g	mm		g	g	g
Forward facing P3 manikin								
Conventional framed CRS L & D retained					3525	66	61	85
Conventional molded plastic CRS, L & D retained	3176	40	44	454	3535	52	46	85
Prototype CRS. Two rigid lower fixings + top tether	3198	26	35	320	3538 3568	Failed to latch Failed to latch		
Prototype CRS. Two lower straps + top tether	3177	32	35	527	3537	53	42	91
Rear facing P3/4 manikin								
Rigid molded plastic CRS, L & D retained	3239	31	39	600	3542	80	110	100
Molded polystyrene CRS, L & D retained					3541	105	107	108
Prototype CRS. Two rigid lower fixings + top tether	3237	27	25	387	3549	64	86	90
Prototype CRS. Two lower straps + top tether	3250	42	45	552	3554	66	85	103

Figure 13.38 Intrusion panel tests Vs non intrusion panel tests (ECE R44 03 belt anchor positions)

For the intruding structure test it is evident that the size, mass and particularly the rigidity of CRS attachment is significant. This is particularly evident with the larger CRS employing rigid attachments where insufficient energy is available to move/deform the seat sufficiently, a situation not evident in the vehicle tests (see discussion, chapter 14). Although conducted at a lower velocity than the existing sled based side impact test, the effect of the manikin/CRS striking intruded structure produces an increase in occupant deceleration levels. However, when reviewing the forward facing 15 kg occupant the increases are not large compared with the lateral CRS acceleration levels. This can be attributed to the head and chest being in close proximity to the hinge about which the intruding panel rotates and, hence, making contact at a much lower velocity. The situation is reversed when considering rear facing infants. In the simulated rear seat evaluation of a rear facing device the head is in close proximity to the vehicle 'B' pillar, potentially the point of maximum intrusion. In these cases, the head and chest acceleration levels are much higher, particularly if less rigidly retained/lighter and is a cause for concern.

14. DISCUSSION

The aim of this research was to study the effects of current and proposed restraint systems on child occupants of vehicles. Whilst dynamic performance in an accident is the principal measure of its efficacy, the importance of other factors is clearly evident.

General comments

The CRS is a component part of a comprehensive restraint system. The purpose of any restraint system is the mitigation of injury to the occupant, but injury is actually the result of a sequence of inter-connected events that constitute an impact. Whilst the CRS is a key element of the restraint system, any of the system elements may affect the type and severity of injury and it is important therefore, that all the elements of the system are compatible and perform optimally.

The modern motor vehicle body structure comprises 'crumple zones' fore and aft of a rigid 'safety cage' within which the CRS and its occupant are secured. In a frontal accident the crumple zone absorbs the energy of impact whilst the design of structural members deflect impact forces away from the safety cage. This safety cage is sufficiently rigid to prevent intrusion in impacts up to 50 km/h, and large enough to allow a restrained occupant controlled forward movement without contacting the vehicle interior.

If the occupant is closely coupled to the vehicle at impact, then their resulting deceleration will be nearer to that of the vehicle itself. Close coupling is best achieved by simplifying the installation, reducing the number of attachments and by minimising slack in the attachments/belts. Ideally a restrained occupant should decelerate at a constant rate over the maximum distance possible without contacting the interior of the vehicle.

The vehicle/CRS and CRS/occupant interfaces are therefore fundamental factors, as they determine the orientation of the occupant with respect to the impact direction and control the load path through the belts and harnesses that significantly affect the loading on vulnerable areas of the body.

Injury tolerance levels of vehicle occupants depend upon age, mass, physical development and health. Restraint design is therefore tailored to the particular occupant group at which the device is aimed. Examples of desirable design features of CRS are five point harness with crotch strap, energy absorbing shielding to the side of the head/torso and rear facing seating for the infant occupant to minimise neck loads.

For restrained children the most common location of fatal injuries are to the head, as a result of direct contact with intruded vehicle structure. Mitigating action may be as simple as installing the CRS in the centre rear seating position, hence maximising the distance between the occupant and any potential intrusion. If combined with rigid (Isofix type) anchors to effectively limit CRS motion within the vehicle this could offer significant benefits.

Such an ideal situation is not always possible. Older vehicles will not have Isofix, and some still do not come equipped with the preferred lap and diagonal belt in the centre rear seating position. However, even in such vehicles, a modern, well installed rear seat positioned CRS will afford acceptable levels of protection. Even an adult belt alone is desirable if no CRS is available to prevent ejection but, as the results shown in chapter 10 indicate, the child could be subjected to excessive acceleration levels due to the belt stiffness and geometry. It is however of interest to note that fatality studies [3.6] have indicated 'overall there is little evidence of a major risk of life threatening neck injury being caused by the diagonal section of the adult belt, except perhaps for very young children'.

Non contact, inertial induced injuries to occupants of CRS are not common. However compression of the spinal column due to excessive acceleration of the torso towards the head is defined in the R44 standard as unacceptable. This does seem to be an area where more research is desirable as unpublished research communication with persons associated with the regulatory body responsible for the R44 standard indicate the standard may be amended to reflect tensile spine loading, (i.e. excessive acceleration of the torso away from the head). The lack of detailed infant/child neck tolerance limits with respect to direct tensile/compressive loads, shear loads and induced bending moments is of concern.

Car occupant accident data for the 25 year period up to 1996 shows a continuing slow decline in serious/fatal injuries to younger children (0-4 years) when weighed against increasing vehicle traffic. For older children (5-9 and 10-14 years) the decline in numbers exposed to serious injury has been less marked.

In recent years CRS development has been focused at the 0-4 year group, particularly with respect to frontal impact. Further it is shown that usage of restraints by this young age group is greater than for the older (5-9 and 10-14 year) groups. It follows, perhaps, that if continued employment of restraints once the child becomes older could be achieved, an improvement in the injury statistics may result.

Current improvements in child occupant passive safety have primarily been driven by legislation, including compulsory usage requirements and improved certification standards for CRS. The recent changes in the European standard ECE R44 (amendment 03) have resulted in a considerable improvement in some product designs, making them more compatible with the modern vehicle restraint types/adult belt geometry.

Side impacts however pose a potentially greater threat to the restrained child than the more common frontal type impact. The benefit of CRS evaluation in side impacts has been discussed (Chapter 13) and an outline test procedure proposed. Products with improved side impact protection will only be developed when a side impact test with realistic performance criteria becomes mandatory, and the introduction of such a test into R44 is strongly recommended.

The performance of current belt retained CRS types

Booster seat type CRS employing the adult belt as the sole interface between the occupant and vehicle are approved for use by children as young as 9 months. Whilst such devices can comply with the dynamic requirements of the current ECE R44 standard, producing, due to good occupant coupling, an acceptable head excursion and deceleration response, they only work well if the occupant is ideally positioned with respect to both the shoulder and lap sections of the adult belt. Not only is there a potential for submarining in a poorly fitted device, but location of the shoulder belt is extremely problematical. Only a very small alteration of the diagonal belt position over the shoulder can result in undesirable position with respect to the neck, or occupant roll out from adult belt during a frontal impact. Children come in many shapes and sizes but CRS manufacturers only have to certify their products with the approved 50th%ile manikins, leading to belt guides being tailored to suit only these dimensions. This, and the tendency for children to move, even slide out of the diagonal belt, makes these type of devices less than ideal for the very young child.

The recent European standard revision ECE R44 (03) has resulted in an improved belt retained CRS-vehicle interface in modern vehicles despite reflecting representative anchorage positions and inertia reel retractors in the approval test. As a result there have been significant advances, especially in group 1 (harness type) CRS design to comply with the revised standard. This is particularly so with respect to CRS/belt geometry and with the addition to the harness of shoulder grabber pads.

The benefit of these shoulder grabbers on a manikin with standard (R44 approved) pyjama type clothing has been proven, and a limited series of tests conducted by the writer indicated the effect is continued if additional clothing is employed. However, no data are available as to the effect with a real child whose thorax is constructed differently from the P3 manikin. Manikins with improved biofidelity would therefore be of benefit for approval purposes.

The UK usage rates for CRS are influenced not only by mandatory requirements but, just as importantly, convenience and ease of installation. It must be remembered that the advances in dynamic performance of CRS are only realised if they are not mis-installed or misused. Regular surveys have consistently reported a very high level of incorrect use such as inappropriate device/seating position, incorrect harness adjustment[1], wrong adult seat belt routing, buckle interference or loose fitting. The most recent UK survey expresses concern with over 80% of all the devices checked. These concerns primarily relate to the interface between the CRS and the vehicle or, in a small number of cases, damaged or defective CRS.

Unfortunately many opportunities for incorrect installation still exist. These concerns range from adult belt mis-routing, incorrect belt/harness tensioning, to the tendency for ' buckle crunching' on the framed CRS. Buckle crunching, evident on about 15% of devices checked, may cause adult belt buckle failure on impact due to loading in bending. To address this concern a number of R44 03 framed CRS offer an alternative routing which

[1] Group (0, 0+, 1) devices

provides a satisfactory method of installation allowing the buckle to lie under the CRS, although this does not meet certain dimensional requirements within the standard. Future amendments to the R44 standard should recognise the buckle crunching concern and for 'universal' devices incorporate a mandatory alternative routing to facilitate installation using adult belts with 'long' buckle stalks, still common in the vehicle fleet.

The Isofix concept is intended to overcome many of these installation concerns by introducing a dedicated CRS interface with the vehicle.

Isofix CRS types

Isofix addresses the deficiencies evident in the CRS/vehicle interface with current belt retained devices (primarily groups 0, 0+ and 1) by replacing the adult belt with dedicated rigid fixings to secure the CRS directly to the vehicle structure. Isofix, in its original four point configuration, offers the benefits of isolating the CRS completely from the vehicle seating, a factor that adversely affects the impact performance of conventional belt retained devices. This particular advantage has been partly compromised by the development of the more easily packaged two point CRS (in seat bight) plus an anti rotation device.

The effect of this change opens the possibility of using a top tether to prevent rotation (as with Causfix). However the use of a top tether is opposed by some sections of the European motor industry on the grounds of complexity and the known low usage rates with systems that incorporate top tethers. In Europe at present the favoured Isofix anti rotation device is a two point rigid anchor device incorporating cushion pre compression within the CRS mechanism (as with Deutschfix). Vehicle specific CRS of this type are currently in production in Europe. If this type of device is to be 'universal', (e.g. after market devices), CRS will have to accommodate the variety of vehicle seat cushions of different length, depth, stiffness and profile currently found in existing vehicles. The performance of this type of CRS has been evaluated in a variety of vehicles although the results are confidential at the time of writing so no reference may be made to the 'in vehicle' performance in this document.

The above rigid anchor devices all require vehicle modification to incorporate the anchorage pins in the appropriate seating positions. In practice, it is unlikely that the anchorages will be retro-fitted in older vehicles and Isofix anchorages are more likely to appear in new models (platforms). Inevitably there will be considerable delay before Isofix fixings become common in the vehicle fleet. For this reason the final Isofix concept (Ucrafix) discussed in this study was promoted.

Ucrafix (initially favoured by some US vehicle manufacturers) with its two soft lower straps and top tether can be fitted more easily to existing vehicles and this should accelerate its introduction in countries that adopt it even though its dynamic performance compares less favourably with rigid anchors, particularly in side impacts.

The Isofix frontal impact results confirm that improved coupling between the vehicle/sled and occupant enhances the dynamic performance of the system and hence protection afforded to the occupant. Head excursion is minimal with the most closely coupled 4 point device although it increases as the coupling is compromised with the other devices. It is important to place on record that for all of the forward facing Isofix devices head excursions are notably (9% for group 1 (P3) Deutschfix and 36% for group 1 (P3) 4 point Isofix) lower than for the current production belt retained devices, as are the induced resultant chest acceleration levels (11% and 14% respectively). However, one noticeable area of concern was with rear facing Group 1 CRS where the occupant was seen to ride up the back of the seat, the head projecting above the protection offered by the seat shell. This was particularly evident in the two point type CRS (no top tether) where excessive head excursion was clearly evident as the seat rotated about the two lower fixing points, the harness playing a larger role in deceleration of the occupant.

Apart from the 4 point, all the Isofix devices may be installed in a manner that could introduce slack into the system. All devices showed a degree of sensitivity to the slack in the attachment with increased head excursion and resultant chest acceleration. Overall, the two point with top tether device (Causfix) was the least sensitive particularly with respect to the important head excursion criteria. However, in such devices that require a top tether (Causfix and Ucrafix) its omission resulted in a significant degradation of performance, with more pronounced head excursion in the case of Ucrafix. The higher resultant head accelerations with the Causfix without the top tether did indicate the possibility for concern as the CRS bottoms out.

Side impact evaluation of Isofix CRS's was based on the New Zealand side impact test (NZS 5411:1991), which does not include any representation of vehicle side structure. Occupant head motion and acceleration levels in a sideways direction were measured. The group 1 (P3) forward facing CRS showed clearly that a rigid interface with the vehicle/sled was beneficial in terms both of resultant acceleration levels, giving improvements (25% for Deutschfix and 30% for 4 point Isofix) compared with current production belt retained devices and with respect to relative motion on the test bench giving improvements (30% and 36% respectively).
The group 1 (P3) 4 point Isofix again produced the lowest acceleration response when subjected to a rear impact.

A user perceived advantage of the Isofix system of CRS attachment will be evident in simplified installation and removal of the device. Improvements in dynamic performance will be less obvious. Draft proposals for Isofix CRS approval for consultation purposes [14.1] include detailed amendments to the current ECE R44 (03) standard with respect to the dynamic performance criteria and also relate to the new 'Isofix' features. To produce improvements in occupant protection, the proposed Isofix CRS dynamic performance parameters are more demanding than the existing requirements. However, there would be a disparity in 'safe' limits as defined for conventional and Isofix CRS which may be difficult to reconcile.

The Isofix interface itself may not be entirely concern free. Apart from taking time to become available in the vehicle fleet, factors such as cost, occupant ride quality and system complexity remain to be fully considered. The issues are discussed below.

Potential Isofix concerns and observations

Conventional adult belt retained CRS have many shortcomings (Chapters 3 and 10) that will be overcome by the Isofix system with improved occupant safety. However, there must be reservations about the Isofix system itself. Some of these are referred to below.

Complexity

Current belt retained CRS are relatively simple devices having few components which can malfunction. The Isofix systems so far produced, although technically superior, do have the potential drawback of complexity, especially in the vital area of the latch interface.

Dedicated CRS attachments will have to offer a very high level of reliability. The draft R44 Isofix amendment currently specifies a visible, audio or tactile indication of latching when the restraint is occupied. Any latch failure will result in asymmetrical loading of the remaining anchorage(s) and the possibility of complete failure (the draft R44 Isofix amendment calls for features that make it impossible to latch only one of the two lower attachments). The potential complexity and fundamental importance of the Isofix latches dictates that clear and unequivocal warning of mal-function is included within the system. The attachment points on the vehicle consist of Ø6 mm x 25 mm long pins situated in the seat bight of both front and rear passenger seating positions. The pins, for reasons of adult seat occupant safety, are recessed approximately 70 mm behind and 10 mm below the seat CR point (it is undesirable to have the steel pins any closer to an adult's spine due to the potential for injury in a rear impact). This dictates that the pins will be located at the lower end of two tubes in the seat bight, with the possibility of being obstructed by foreign bodies.

Occupant Positioning (Adjustment to suit vehicle seat geometry)

With current belt retained CRS it is important to position the upper torso and head of the occupant as far back as possible in the normal installed condition for maximum occupant ride down distance in an impact. Any Isofix CRS will likewise have to conform with this requirement to optimise its performance. With vehicle seats varying in dimensions and shape it may be necessary for CRS to include a range of adjustments to conform with the universal concept of Isofix. It would be counter-productive if Isofix CRS were approved as vehicle specific, negating the universal concept.

Ride Quality

Ride quality for occupants of vehicles is a complex subject beyond the scope of this research, but much data is available on the subject. It is clear that both magnitude and frequency of accelerations in all directions play a part, some more significant than others. Further, seating will attenuate the transmission of vibration to the occupant, depending upon the input levels.

Vehicle seats are designed to provide a compliant yet supportive (both vertically, horizontally and laterally) seating system for adults. Vehicle manufacturers produce seating to meet their own specifications and the standards for individual vehicle types cover occupant mass ranges from 95%ile male to 5%ile female. Historically the child occupant has never been specifically considered with respect to ride quality. However it would be reasonable to conclude that the seat cushion may be excessively stiff for the significantly lower mass of a child occupant seated directly upon the vehicle seat.
The situation is redressed slightly in conventional CRS systems, as the CRS itself possesses a mass. If we consider forward facing occupants in a Group 1 CRS the combined CRS/occupant mass will be in the 20-30 kg range and closer to the 50 kg of the smallest female.

The Isofix CRS systems which attempt to remove the seat cushion effect during impact may reduce occupant ride quality, effectively leaving the child to travel in a plastic shell attached to the floor pan of the vehicle. As a consequence, the only compliant medium between child and road would be the vehicle suspension system and tyres. The issue of ride quality for the child occupant of Isofix CRS has not been widely addressed in the many Isofix deliberations, however unpublished research by a major UK CRS manufacturer in conjunction with an automobile company suggests that the four point Isofix CRS produced no concern in the area of occupant ride quality. This may be the case in the specific vehicle types evaluated, but even a two point system relying on the vehicle seat cushion to control the acceleration levels in one of the six degrees of freedom may warrant further evaluation given the variety of vehicles in which a 'universal' type Isofix CRS could be installed.

<u>Cost</u>

Any Isofix CRS remains essentially a conventional system with added components and added costs. There is little in the current adult belt retained CRS that will become obsolete with the introduction of Isofix, so there will be little scope for cost saving. Further, due to the relatively small number of suitably equipped vehicles, the first 'universal' Isofix CRS will need to be multi-purpose for deployment as a conventional belt retained CRS as well as having (fold away) Isofix fixings. This implies considerable extra manufacturing costs. The retail price thus becomes a factor in the Isofix debate especially if this is significantly greater than the cost of a conventional CRS. The North American Isofix user study [11.7] suggests that the manufacturers' on-cost associated with any of the new attachment concepts could not be passed on to the customer if the retail price was 50% more than an average conventional CRS.

In addition to the added complexity of latches, interlocks and tensioning ratchets (for the Deutschfix type) there is also the added cost to the vehicle. This increased vehicle cost due to the Isofix pins on the platform/front passenger seat and the addition of top tether anchorages (if specified) will apply to all vehicles.

Enhancement of the Isofix System

Work was carried out to develop an energy absorber (Appendix 5) to capitalise on the benefits already offered by the Isofix framed group 1 CRS in a frontal impact. However, the potential benefits did not warrant further work. Although the device developed enabled a measurable lowering of occupant loading (but with increased head excursion) the fundamental drawback of a load sensitive device was clear. Since triggering of the device is required at a pre-determined load the final product has the limitation of being both occupant mass and acceleration level sensitive. Since these two factors can both vary considerably, the device will:

- be of no benefit at all, i.e. fail to function, should the combination of mass and deceleration pulse not reach triggering levels; or
- function correctly; or
- in the case of a severe input, potentially be detrimental to the occupant by effectively introducing a loading spike in the system as the energy absorber reaches full extension.

Overall, therefore, the practicability of any pre-set load sensitive energy absorber must be limited by the factors mentioned above.

Fundamentally it is head excursion resulting in head contact that is the primary consideration, not necessarily inertial acceleration levels. Preventing occupant contacts must be the priority of any restraint.

Details of the work conducted on energy absorbers, devices built and results are given in Appendix 5.

The effect in a frontal impact of CRS recline angle

In currently available conventional forward facing Group 1 CRS, occupants may be restrained at seat base inclination angles ranging between 30° to 45° to the horizontal in the 'upright' position when installed upon a vehicle seat cushion. However, the angle may be considerably increased in those CRS offering a recumbent position. The maximum installed seat base inclination to the horizontal recorded with a commercially available CRS on the R44 test bench being 60°.

At the larger recline angles occupant horizontal head travel, the major criteria, increases significantly in both the conventional belt retained and the Isofix systems (the 4 point Isofix does not change its angle with respect to the vehicle during the event). At a 60° seat base angle, the forward head travel is greater than in a typical upright position (seat base 30° to the horizontal) by 23% in the Isofix system and 8% in the conventional system (P3 manikin). If we take as a baseline the slightly unrealistic condition of a seat base at 0° to the horizontal, the head travel with a seat base at 60° to the horizontal in the Isofix system can be seen to be up to 80% greater. Further, in the case of the Isofix system both the chest and head response of a P3 manikin were also increased. It should also be noted that the neck loading recorded in this manikin increased as the angular velocity of the head increased, with greater CRS recline again peaking in the 50°-70° seat base inclination region.

The rear facing Group 1 CRS (P3 manikin) was also surprisingly sensitive to recline angle with chest and head acceleration levels rising notably once the recline angle exceeded 20°, the chest approaching the ECE R44 limit of 55 g at a seat base recline angle of 40°, this being 46% greater than with a seat base inclination of 0°.

Whilst it may not be practical to design CRS that sit the occupant absolutely upright, with a seat base inclination of 0°, it does however appear desirable to keep as close to that ideal position as practicable to optimise the performance of a device. CRS that offer a recumbent position may appear desirable from a comfort and convenience perspective, but they do not offer the same level of impact performance as an upright device.

Side impacts

Analysis of side impact accidents in which a restrained child occupant was seriously injured or killed [3.6] concluded that this accident type is potentially more serious in terms of occupant outcome than the more common frontal incident. This is because occupants seated on the impacted side of the vehicle are unable to avoid high energy intruding structure.

ECE R44 focuses on the crash performance in frontal and rear impacts[2] and does not require dynamic evaluation in a side impact. To address this omission work was completed to develop a practical single sled test to reproduce input characteristics of a typical side impact accident. The test was based on the existing side impact evaluation of Australian and New Zealand CRS acceptance standards with the addition of an element to represent the intrusion observed in real side impact accidents. Impact direction, profile and velocity were based upon accident data and the sled parameters to be reproduced were obtained from full scale vehicle tests.

The test employed an auxiliary impactor to actuate a panel representing intruding structure. The sled/panel parameters were based upon data obtained from the vehicle tests, and the effectiveness of the test evaluated by comparing the sled/vehicle manikin responses.

The concept of an intruding panel side impact test offers potential advantages over current performance evaluations for existing CRS retained by adult belts. However the proposed test does not impart sufficient energy to adequately evaluate the very rigidly retained CRS as with Isofix. Furthermore, it is evident that additional development of the structure of the intruding panel is needed to realistically represent that of a typical vehicle.

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[2] Group 0 and 0+ rear facing

The test procedure developed offers a basis to more realistically assess the lateral impact performance of CRS when the child's head is close to the area of likely maximum intrusion during a side impact accident, particularly rear facing infant carriers on the rear seat.

It is apparent that an energy based rather than velocity based criteria to define the intrusion panel input may be of advantage particularly when assessing the performance of rigidly attached CRS types. The practicality however of a high energy sled test evaluation is doubtful.

It is evident that mitigating injury in a side impact is two-fold:

- Preventing the CRS from moving relative to the vehicle shell, and thus impacting any intruding structure.

- The CRS itself having sufficient energy absorbing material of sufficient dimensions to the side to contain the occupant within the shell avoiding direct contact between the occupant and vehicle.

It is clear from the work conducted that a rigid Isofix interface with the vehicle will improve the former, particularly in the centre or non-struck side condition. However the enhancement of the protection offered by the shell and energy absorbing medium will require the introduction of a suitable test to not only drive manufacturers to improve side impact protection, but furnish them with a tool to enable the development of such improvements.

Summary

Many serious and fatal injuries to restrained children in frontal and side impacts are due to contact with the vehicle or an intruding object. If contact occurs at the extremes of the occupant ride down zone, it is possible that the injury may be avoidable or minimised by reducing occupant excursion. There are few instances of fatalities due to inertial loading as a result of high non contact 'g' forces, although it is not unknown Roy et al [3.17]. The current generation of R44 03 approved products have in tests been shown to work effectively in longitudinal impacts, but only if installed and used correctly. They have

however in their adult belt retained form reached a level of performance it will be difficult to surpass due to the interaction with the vehicle belts and seat cushion. Isofix, in its rigid anchor form, will offer a solution to not only the current installation concerns, but also provide a significant enhancement in impact performance due to the improved coupling to the vehicle structure which will reveal itself not only in frontal accidents, but in the potentially more demanding side impact incident. Providing the concerns of cost and complexity can be overcome, Isofix will be a major step forward in CRS design for group 0, 0+ and group 1 devices.

The statistics suggest, however, that occupants of the slightly older age groups (CRS groups 2 and 3) may be benefited by simply increasing the usage rate. These groups will not be directly affected by the introduction of the Isofix interface, as they use the adult belt as the primary restraint.

Further opportunities to enhance child occupant safety will come from revisions to the acceptance standard, both minor, (e.g. elimination of the potential for 'buckle crunching' on framed CRS), and more major, by the introduction of a representative side impact evaluation. Finally, it would be desirable if realistic tolerance limits could be established to include a measurement of neck loading induced by the various CRS configurations/types, however the biofidelity of manikins will require improvement to complement this.

15. CONCLUSIONS

The objective of the research programme was to review the effectiveness of existing automobile CRS and to assess the potential advantages and disadvantages of proposed 'improved' systems.

It must initially be recognised that at present it is not possible to prevent all injury to vehicle occupants in every impact. High energy accidents will always present the potential for exceeding the design criteria of the vehicle's protective safety cell with subsequent intrusion into the passenger compartment and contact between the occupant and vehicle interior. This is a significant concern with respect to injuries to children. Some accidents, particularly side impacts, are going to be so severe that direct high energy contact with the occupant is inevitable and in reality unavoidable in spite of the restraint system. It is in the less severe accident that improvements in restraint design and usage will show benefits. By improving the coupling with the vehicle a reduction in the excursion of an occupant within the vehicle during an accident will be achieved thus lowering the risk of contact. Further, improved coupling of the occupant to the vehicle will have the benefit of lowering occupant acceleration levels. This should, when combined with a reduced risk of contact, lower the risk of induced injury such as to the neck.

However, performance in an accident is not the only criteria by which a CRS should be judged. By and large, the current generation of adult belt retained CRS fulfil their intended function; they offer an adequate level of dynamic performance in a frontal impact and they are universal enough in their fitting to encourage usage. Nevertheless there is concern with respect to current devices: a significant number of CRS are incorrectly fitted. Mis-installation or misuse of even the best performing devices can degrade dynamic performance and sometimes cause failure, resulting in injury. It is the interface between the CRS and vehicle that presents the greatest problems with CRS. CRS must be installed on the correct attachment points and tensioned/adjusted to at least the minimum prescribed level.

Simplicity and ease of installation are the major factors behind the 'new' Isofix concept of child restraint interface with the vehicle. The advantage such systems offer is simple, essentially universal, deployment eliminating the complexity of adult belts. Further, the use of rigid anchors has the benefit of a significant improvement in CRS vehicle coupling with commensurate improvements in dynamic performance.

The advantages afforded by the rigid Isofix concept are not confined to frontal impacts. Side impact performance, a neglected area of CRS design, is also improved when Isofix attachments are deployed. This is particularly the case for a centre or non-struck side seated occupant who, if retained within the CRS shell, could avoid contact with the vehicle structure altogether.

The Isofix interface with the vehicle offers benefits to the restrained child occupant but Isofix itself presents concerns. Package constraints have already driven industry into rejecting the 4 point Isofix system, with the superior coupling to the vehicle, in favour of the 2 point system with anti rotation device. With only two couplings securing the CRS and occupant to the vehicle not only will the reliability of any latch interface will be of paramount importance, but the use of an anti-rotation feature has, particularly in the case of rear facing CRS, been shown to be highly desirable.

Although the issues of installation and performance are important, other factors also play a role.

In recent years CRS development mainly with respect to frontal impact has focused at the 0-4 year group, where the usage of restraints is highest. Accident data relating to younger children continues to show a steady improvement when weighted against increasing vehicle traffic, but for older children the improvement has been less marked.

Current improvements in child occupant passive safety are primarily driven by legislation on compulsory usage requirements and improved approval standards.

The recent changes in the European standard ECE R44 (amendment 03) have resulted in improved belt retained product designs, making them more compatible with the modern vehicle restraint types/adult belt geometry. This has addressed concerns associated with modern vehicle adult belt geometry but still leaves the issues of mis-installation and misuse outstanding. With respect to poor routing/loose adult belts, apart from simplifying designs, improved installation instructions are needed for greater compliance. It is feasible and desirable that future amendments to the R44 standard should recognise the concerns about 'buckle crunching' and, for 'universal' devices, incorporate a mandatory alternative routing to facilitate installation on adult belts with 'long' buckle stalks.

A more fundamental change to the R44 standard would involve the introduction of a dynamic test procedure simulating a vehicle side impact, arguably the most dangerous type of impact with respect to occupant protection. This is the only way to drive manufacturers into producing CRS with realistic performance for side impact protection.

The issue of acceptable levels of neck loading requires further research. Non-contact inertially induced neck loads can vary depending on the seat type and the occupant's orientation. Isofix will reduce the level of these loads. The current R44 standard, however, lacks any measurement of neck loading, partly due to the limited biofidelity of the current generation of manikins employed for approval, and partly to the lack of data relating to tolerance limits.

The draft proposals for an amendment to the ECE R44 standard to reflect Isofix type CRS includes modifications to the fundamental dynamic compliance criteria. It is proposed that in a frontal impact, an Isofix CRS incorporating a top tether, a beneficial feature, will be required to meet more stringent compliance criteria than a conventional or an Isofix CRS without top tether. It is anticipated that such a tightening of the standard will drive manufacturers to improve the performance level of the restraint system and hence produce clear beneficial improvements in occupant safety. Isofix will hence offer a new level of CRS performance which it is anticipated will eventually replace the current devices as the accepted norm.

Finally, the market in Europe, particularly in the UK, has dictated that Group 1 forward facing CRS, other than those at the economy end of the market, include features to recline a child into a supine mode. From the research conducted it is evident that both front and rear facing group 1 CRS perform at their best in their upright configuration, although this may not be practical in all circumstances. The effects with respect to forward facing CRS are particularly important with head excursion a major factor. With such CRS any seat base inclination approaching 60° is considered undesirable from the point of view of not only those parameters defined in R44, but in addition to minimise neck loadings.

Whilst it may not be practical to design CRS that sit the occupant completely upright, it does appear desirable to keep as close to that ideal position as practicable to optimise the performance of a device. CRS that offer a recumbent position may appear desirable from a comfort and convenience perspective, but they do not offer the same level of frontal impact performance as an upright device.

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8.1 FACTORED RESULTS

	Head res g	Chest res g	Chest Z tension g	Chest Z comp g	Excursion mm	Head res/ B'line	Chest res/ B'line	Chest Z/ B'line	Excursion/ B'line	Excursion/ B'line	Excursion/ 550
EA in Harness P3 ATD											
Mk 1 Polymer EA											
3124	N/A	39	28	16							
3125	N/A	39	28	3			1	1	0.19		
3126	N/A	40	35	1			1.03	1.25	0.06		
Shear Type EA											
3124	N/A	39	28	16							
3127	N/A	51	36	4			1.31	1.29	0.25		
Friction EA											
3125	70	49	32	11		0.86	0.76	0.84	0.91		
3260	60	37	27	10							
Mk 2 Polymer EA											
3131	N/A	44	35	15							
3266	60	39	33	12							
3304	63	46	31	18	326						0.59
3303	69	43	29	13	357	1.10	0.93	0.94	0.72		0.65
Shear Type EA											
3131	N/A	44	35	15							
3266	60	39	33	12							
3302	62	32	21	11	364	1.03	0.82	0.64			0.66
3306	70	38	31	11	376	1.17	0.97	0.94			0.68

Corrugated type EA

3131	N/A	44	35	15							
3266	60	39	33	12							
3308	63	45	31	15	339	1.05	1.15	0.94	1.25		0.62
3309	71	43	28	14	345	1.18	1.10	0.85	1.17		0.63
3305	71	37	29	10	364	1.18	0.95	0.88	0.83		0.66
3307	78	38	25	12	414	1.3	0.97	0.76	1		0.75
3310	62	43	34	16	357	1.03	1.10	1.03	1.33		0.65

Corrugated type EA with Shear Pin

3404	68	44	34	19	330						0.60
3405	76	45	29	19	316						0.57
3406	72	39	33	19	358	1.06	0.89	0.97	1	1.08	0.65
3407	71	39	30	18	372	1.04	0.89	0.88	0.95	1.13	0.68
3408	78	41	34	20	393	1.15	0.93	1.00	0.95	1.19	0.71
3409	69	42	32	17	393	1.01	0.95	0.94	0.89	1.19	0.71
3410	69	41	23	15	393	1.01	0.93	0.68	0.79	1.19	0.71
3411	61	40	25	17	358	0.90	0.91	0.74	0.89	1.08	0.65
3412	65	42	31	15	351	0.96	0.95	0.91	0.79	1.06	0.64

Tight Harness - No 25mm block]

3414	61	37	32	12	316						0.57
3415	65	36	26	12	337	1.07	0.97	0.81	1	1.07	0.61

Std CRS v ISOFIX and CANFIX

3580	65	47	20	14	643	1.16	0.96	0.59	0.82	1.77	1.17
3578	62	50	16	15	602	1.11	1.02	0.47	0.88	1.65	1.09
3607	56	49	34	17	364						0.66
3582	62	48	18	15	430	1.11	0.98	0.53	0.88	1.18	0.78

CANFIX with EA in TT

3582	62	48	18	15	430						0.78
3583	50	42	17	15	466	0.81	0.88	0.94	1	1.08	0.85
3584	45	37	14	9	473	0.73	0.77	0.78	0.8	1.10	0.86

4 point ISOFIX with Harness EA

3607	56	49	34	17	364						0.66
3604	63	43	31	14	408						0.74
3605	76	44	37	13	376	1.21	1.02	1.19	0.93	0.92	0.68
3606	69	40	32	14	376	1.10	0.93	1.03	1	0.92	0.68

Programme using P3/4 ATD

Std CRS v ISOFIX and CANFIX

3619	66	52	11	12	521						0.95
3620	60	48	9	11	521						0.95
3608	61	42	19	16	364						0.66
3625	47	40	12	17	332						0.60
3626	46	42	19	13	326						0.59

CANFIX with EA

3630	48	46	26	11	333						0.61
3626	46	42	19	13	332						0.60
3627	48	43	16	15	333	1.04	0.98	0.84	1.15	1.00	0.61
3628	45	41	21	14	375	0.98	0.98	1.00	1.08	1.13	0.68
3629	50	42	14	11	354	1.09	1.00	0.74	0.85	1.07	0.64

CANFIX

3652	48	41	26	11	354						0.64
3640	53	41	28	17	340						0.62
3651	43	35	13	9	417	0.81	0.85	0.46	0.53	1.23	0.76

P3 Tests Frontal impacts

Test	CRS description	Set up on sled	CRS factors	Man	3 ms Head res	Chest res	Chest z tension	Chest z com'p	Excursion beyond CR	Harness loads Upper harne's loads	Lap sect'n loads	Crotch strap loads
					g	g	pos'g'	neg'g'	mm	KN	KN	KN
3305	ISOFIX 4 point pivoting (30 deg) with the Paton corrugated type (1mm thick) steel energy abs	Pivot buck	Approx 30mm stroke aceived	P3	71	37	29	10	364	0.78	0.95	0.61
3306	ISOFIX 4 point pivoting (30 deg) with the Paton shear type (0.75mm thick 'Sierra') steel energy abs	Pivot buck	Approx 40mm stroke acheived	P3	70	38	31	11	376	0.76	1.00	0.55
3307	ISOFIX 4 point pivoting (30 deg) with the Paton corrugated type (0.75mm thick 'Sierra') steel energy abs	Pivot buck	Approx 100mm stroke acheived	P3	78 noise	38 noise	25	12	414	1.05	0.89	0.61
3308	repeat of 3305 with shear pin 5mm dia	Pivot buck	No activation	P3	63	45	31	15	339	0.93	0.83	0.74
3309	repeat of 3305 with shear pin 5mm dia with 1mm dia hole in it	Pivot buck	No activation	P3	71	43	28	14	345	1.05	0.82	0.83

P3 Tests Frontal impacts

Test	CRS description	Set up on sled	CRS factors	Man	3 ms Head res	3 ms Chest res	3 ms Chest z tension	3 ms Chest z com'p	Excursion beyond CR	Harness loads: Upper harne's loads in front of shell	Harness loads: Lap sect'n loads	Harness loads: Crotch strap loads
					g	g	pos'g'	neg'g'	mm	KN	KN	KN
3310	repeat of 3305 with shear pin 5mm dia with 2mm dia hole in it	Pivot buck	25mm activation	P3	62	43	34	16	357	0.81	0.91	0.59
3404	Base line for the following ISOFIX 4 point pivoting (30 deg) with the Paton Mk1 rectangular corrugated type (1mm thick) steel energy abs	Pivot buck	No activation bolted up, baseline	P3	68	44	34	19	330	1.46	1.19	N/R
3405	ISOFIX 4 point pivoting (30 deg) with the Paton Mk1 rectangular corrugated type (1mm thick) steel energy abs 5mm delrin 2mm hole	Pivot buck	No activation (Should have been) ie another baseline test	P3	76 noise	45 noise	29	19	316	1.56	1.11	N/R
3406	ISOFIX 4 point pivoting (30 deg) with the Paton Mk1 rectangularcorugated type (1mm thick) steel energy abs 5mm delrin 3mm hole	Pivot buck	Activation 30mm stroke	P3	72	39	33	19	358	1.44	0.90	N/R
3407	ISOFIX 4 point pivoting (30 deg) with the Paton Mk1 rectangular corrugated type (1mm thick) steel energy abs 5mm delrin 3mm hole	Pivot buck	Activation 35mm stroke	P3	71	39	30	18	372	1.65	0.87	N/R

P3 Tests Frontal impacts

					3 ms					Harness loads		
					Head res	Chest res	Chest z tension	Chest z com'p	Excursion beyond CR	Upper harne's loads	Lap sect'n loads	Crotch strap loads
Test	**CRS description**	**Set up on sled**	**CRS factors**	**Man**	g	g	pos'g'	neg'g'	mm	KN	KN	KN
3408	ISOFIX 4 point pivoting (30 deg) with the Paton tapered corrugated type (1mm thick) steel energy abs 5mm delrin 3mm hole Still with slotted firing hole as previous	Pivot buck	Activation 44mm stroke	P3	78 noise	41 noise	34	20	393	1.62	0.92	N/R
3409	ISOFIX 4 point pivoting (30 deg) with the Paton tapered corrugated type (1mm thick) steel energy abs 5mm delrin 3mm hole Still with slotted firing hole as previous	Pivot buck	Activation 45mm stroke	P3	69	42	32	17	393	1.88	0.86	N/R
3410	ISOFIX 4 point pivoting (30 deg) with the Paton tapered corrugated type (1mm thick) steel energy abs 5mm delrin 3mm holewith plastic hindge type shear pin	Pivot buck	Activation 48mm stroke	P3	69	41	23	15	393	1.79	0.82	N/R
3411	ISOFIX 4 point pivoting (30 deg) with the Paton rectangular corrugated type (1mm thick) steel energy abs 5mm delrin 3.5mm hole with plastic hindge type shear pin	Pivot buck	Activation 45mm stroke	P3	61 noise	40 noise	25	17	358	1.71	0.70	N/R
3412	ISOFIX 4 point pivoting (30 deg) with the Paton rectangular corrugated type (2mm thick, ie two spot welded together) steel energy abs 5mm delrin 3.5mm hole with plastic hindge type shear pin	Pivot buck	Activation 20mm stroke	P3	65 noise	42 noise	31	15	351	1.61	0.88	N/R

P3 Tests Frontal impacts

					3 ms					Harness loads		
					Head res	Chest res	Chest z tension	Chest z com'p	Excursion beyond CR	Upper harne's loads	Lap sect'n loads	Crotch strap loads
Test	**CRS description**	**Set up on sled**	**CRS factors**	**Man**	g	g	pos'g'	neg'g'	mm	KN	KN	KN
3414	ISOFIX 4 point pivoting (30 deg) with standard harness but fitted tight ie no 1" block down back of manikin (No energy absorber) ie Baseline for next test	Pivot buck	Standard R44 test but with No 1" block ie tight harness	P3	61	37	32	12	316	1.51	1.22	N/R
3415	ISOFIX 4 point pivoting (30 deg) with standard harness but fitted tight ie no 1" block down back of manikin (With rectangular corg't 1mm thick energy absorber)	Pivot buck	Activation 50mm stroke	P3	65	36	28	12	337	1.48	1.16	N/R

P3 Tests Frontal impacts

					3 ms				Excursion beyond CR	Neck loads				
					Head res	Chest res	Chest z tension	Chest z com'p		Peak Neck 'x' shear	30 ms Neck 'x' shear	Peak Neck 'z' tension	30 ms Neck 'z' tension	Mom't Mb @ C'line
Test	**CRS description**	**Set up on sled**	**CRS factors**	**Man**	g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3578	Std freeway L&D with majic pads	Ste ECE R44		P3	62	50	16	15	602	1.53	0.73	2.20	1.20	33.0
3580	Std freeway L&D without majic pads	Ste ECE R44		P3	65	47	20	14	643	1.37	0.69	2.15	1.06	27.7
3582	Canfix freeway with magic pads, std 1.5" TT (30°)	Canfix		P3	62	48	18	15	430	1.73	0.76	2.22	1.25	33.8
3583	repeat of 3582, Canfix freeway with magic pads, plus corrugated energy absorber (single thickness) in Top Tether	Canfix	13.92 m/s	P3	50	42	17	15	466	1.53	0.80	2.01	0.97	28.6
3584	as 3583 but duuble thickness energy absorber	Canfix	13.80 m/s	P3	45	37	14	9	473	1.25	0.74	1.66	0.96	23.0

P3 Tests Frontal impacts

					3 ms					Neck loads				
					Head res	Chest res	Chest z tension	Chest z com'p	Excursion beyond CR	Peak Neck 'x' shear	30 ms Neck 'x' shear	Peak Neck 'z' tension	30 ms Neck 'z' tension	Mom't Mb @ C'line
Test	**CRS description**	**Set up on sled**	**CRS factors**	**Man**	g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3604	Repeat of 3593 Pivot buck with low friction back bar No magic pads (30o)	Pivot buck	14.02 m/s No video U/S	P3	63	43	31	14	408	1.68	0.89	2.22	0.96	34.1
3605	Repeat of 3604 Pivot buck with low friction back bar No magic pads (30o) With the addition of single thickness 3 corrigation EA in harness yoke with shear pin	Pivot buck	13.86 m/s EA activation 37mm	P3	76	44	37	13	376	1.71	0.89	2.30	0.88	32.7
3606	Repeat of 3605 Pivot buck with low friction back bar No magic pads (30o) With the addition of double thickness 3 corrigation EA in harness yoke with shear pin	Pivot buck	14.07 m/s EA activation 25mm	P3	69	40	32	14	376	1.58	0.77	2.11	1.05	30.0
3607	Repeat of 3604 Pivot buck with low friction back bar But with magic pads (30o) No EA	Pivot buck	13.94 m/s	P3	56	49	34	17	364	1.59	0.85	2.15	0.97	31.8

P3 Tests Frontal impacts

Test	CRS description	Set up on sled	CRS factors	Man	3 ms Head res g	3 ms Chest res g	3 ms Chest z tension pos'g'	3 ms Chest z com'p neg'g'	Excursion beyond CR mm	Neck loads Peak Neck 'x' shear KN	Neck loads 30 ms Neck 'x' shear KN	Neck loads Peak Neck 'z' tension KN	Neck loads 30 ms Neck 'z' tension KN	Neck loads Mom't Mb @ C'line Nm
3619	Lap & Diagn'l with majic pads	Std freeway		P3/4	66	52	11	12		1.28	0.81	1.81	1.16	24.3
3620	Lap &Diagn'l without majic pads	Std freeway		P3/4	60	48	9	11		1.13	0.80	1.48	1.11	20.8
3621	Lap belt only without majic pads	Std freeway		P3/4	N/A	42	17	15		N/A	N/A	N/A	N/A	N/A
3622	Lap belt only with majic pads	Std freeway		P3/4	61	41	13	16		1.20	0.70	1.85	0.99	23.0

P3 Tests Frontal impacts

Test	CRS description	Set up on sled	CRS factors	Man	3 ms Head res	3 ms Chest res	Chest z tension	Chest z com'p	Excursion beyond CR	Neck loads Peak Neck 'x' shear	30 ms Neck 'x' shear	Peak Neck 'z' tension	30 ms Neck 'z' tension	Mom't Mb @ C'line
					g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3608	Repeat of 3604 Pivot buck with low friction back bar No magic pads (30o) No EA P3/4 manikin	Pivot buck	14.06 m/s	P3/4	61	42	19	16	364	1.04	0.63	1.52	0.78	21.1
3609	Repeat of 3608 Pivot buck with low friction back bar No magic pads (30o) With the addition of single thickness 3 corrigation EA in harness yoke with shear pin	Pivot buck	13.95 m/s pin sheared but no extension of EA	P3/4	58	40	25	17	364	0.77	0.54	1.34	0.53	13.9
3610	Repeat of 3608 Pivot buck with low friction back bar No magic pads No EA But at (20o)	Pivot buck	14.04 m/s	P3/4	54	40	27	10	332	1.06	0.63	1.48	0.82	22.0

P3 Tests Frontal impacts

Test	CRS description	Set up on sled	CRS factors	Man	Head res g	Chest res g	Chest z tension pos'g'	Chest z com'p neg'g'	Excursion beyond CR mm	Peak Neck 'x' shear KN	30 ms Neck 'x' shear KN	Peak Neck 'z' tension KN	30 ms Neck 'z' tension KN	Mom't Mb @ C'line Nm
3625	Canfix std with magic pads 1.5"tt	Canfix		P3/4	47	40	12	17	332	1.05	0.71	1.45	0.84	18.9
3626	Canfix std with No magic pads 1.5"tt	Canfix	13.52 m/s baseline	P3/4	46	42	19	13	332	1.09	0.70	1.51	0.93	19.2
3627	As 3626 CANFIX no magic pads, but with 5 convolution EA single thichness (1mm thick) no pre trigger shear pin in TT	Canfix	13.35 m/s aprox 50mm activation	P3/4	48	43	16	15	333	1.15	0.70	1.52	0.98	22.0
3628	As 3627 but with double (two togther) EA	Canfix	13.69 m/s aprox 33mm activation	P3/4	45	41	21	14	375	1.17	0.65	1.60	0.83	21.5
3629	As 3627 but with trebel thickness EA	Canfix	? m/s aprox 20mm activation	P3/4	50	42	14	11	354	1.15	0.70	1.43	1.00	21.0
3630	As 3627 but with solid steel strip replacing EA in TT	Canfix	baseline	P3/4	48	46	26	11	333	1.24	0.65	1.70	0.83	24.0

P3 Tests Frontal impacts

					3 ms					Neck loads				
					Head res	Chest res	Chest z tension	Chest z com'p	Excursion beyond CR	Peak Neck 'x' shear	30 ms Neck 'x' shear	Peak Neck 'z' tension	30 ms Neck 'z' tension	Mom't Mb @ C'line
Test	**CRS description**	**Set up on sled**	**CRS factors**	**Man**	g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3640	Canfix with NO ece r44 test seat cushion , no magic pads, stright steel strip top tether	Canfix	13.81m/s	P3/4	53	41	28	17	340	1.18	0.66	1.67	0.83	23.8
3641	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EAdouble thichness (1mm thick) no pre trigger shear pin in TT	Canfix	13.80m/s	P3/4	57	37	21	12	396	1.13	0.72	1.59	0.90	23.2
3642	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EA single thichness (1mm thick) no pre trigger shear pin in TT	Canfix	13.81m/s	P3/4	67	42	17	13	347	1.36	0.60	1.90	0.90	27.8
3643	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EA single thichness (1mm thick) with pre trigger shear pin in TT dia 5mm, hole 3.5mm	Canfix	13.80m/s	P3/4	61	42	19	14	417	1.16	0.70	1.70	0.95	22.7
3644	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EA single thichness (1mm thick) with pre trigger shear pin in TT dia 5mm, hole 2.5mm	Canfix	13.56m/s	P3/4	61	48	14	12	417	1.22	0.73	1.75	1.00	23.5

P3 Tests Frontal impacts

Test	CRS description	Set up on sled	CRS factors	Man	3 ms Head res	3 ms Chest res	3 ms Chest z tension	3 ms Chest z com'p	Excursion beyond CR	Neck loads Peak Neck 'x' shear	Neck loads 30 ms Neck 'x' shear	Neck loads Peak Neck 'z' tension	Neck loads 30 ms Neck 'z' tension	Neck loads Mom't Mb @ C'line
					g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3645	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EA single thichness (1mm thick) with pre trigger shear pin in TT dia 5mm, NO Hole	Canfix	13.63m/s	P3/4	61	49	15	15	433	1.23	0.74	1.85	1.00	24.2
3646	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EA double thichness (1mm thick x 2) with pre trigger shear pin in TT dia 5mm, NO Hole	Canfix	13.68m/s	P3/4	60	43	14	10	424	1.16	0.75	1.67	1.05	23.5
3647	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EA trebbel thichness (1mm thick x 3) with pre trigger shear pin in TT dia 5mm, NO Hole	Canfix	13.68m/s	P3/4	58 noise	43 noise	12	8	410	1.14	0.63	1.72	0.83	21.3
3648	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EA double thichness (1mm thick x 2) with pre trigger shear pin in TT dia 6mm, NO Hole	Canfix	13.60m/s shear pin failed to fire !	P3/4	N/A	41	23	9	382	N/A	N/A	N/A	N/A	N/A
3649	As 3648 but tight harness straps	Canfix	13.59m/s shear pin failed to fire !	P3/4	51	38	24	10	340	1.15	0.58	1.64	0.92	21.7

P3 Tests Frontal impacts

Test	CRS description	Set up on sled	CRS factors	Man	3 ms Head res	3 ms Chest res	3 ms Chest z tension	3 ms Chest z com'p	Excursion beyond CR	Neck loads Peak Neck 'x' shear	Neck loads 30 ms Neck 'x' shear	Neck loads Peak Neck 'z' tension	Neck loads 30 ms Neck 'z' tension	Neck loads Mom't Mb @ C'line
					g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3650	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EA double thichness (1mm thick x 2) with pre trigger shear pin in TT dia 6mm, with dia 2.0mm Hole. ECE R44 03 harness set up ie 1" slack	Canfix	13.65m/s	P3/4	47	40	14	11	410	1.00	0.78	1.31	0.97	18.8
3651	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EA double thichness (1mm thick x 2) with pre trigger shear pin in TT dia 6mm, with dia 2.5mm Hole. ECE R44 03 harness set up ie 1" slack	Canfix	13.67m/s	P3/4	43	35	13	9	417	1.02	0.74	1.41	0.87	19.7
3652	As 3640 but std 1.5" Webbing TT. ECE R44 03 harness set up ie 1" slack	Canfix	13.68m/s	P3/4	48	41	26	11	354	1.26	0.65	1.75	0.90	25.0

Test	Mk1 Polymer EA in harness	0°	P3		Head res	Chest res	Chest z tension	Chest z com'p	Excursion beyond CR	Upper harne's loads	Lap sect'n loads	Crotch strap loads
	CRS description	Set up on sled	CRS factors	Man	g	g	pos'g'	neg'g'	mm	KN	KN	KN
3124 Baseline	ISOFIX 4 point pivoting (0 deg)	Pivot buck	Baseline	P3	N/A	39	28	16		1.61	0.57	0.95
3125 plastic EA	ISOFIX 4 point pivoting (0 deg)	Pivot buck	With plastic Mk1 slot energy abs	P3	N/A	39	28	3		1.46	0.84	1.83
3126 plastic EA	ISOFIX 4 point pivoting (0 deg)	Pivot buck	With plastic Mk1 slot energy abs	P3	N/A	40	35	1		1.70	0.79	1.46

Test	Shear type EA	0°	P3		Head res (g)	Chest res (g)	Chest z tension (g)	Chest z com'p (g)	Excursion beyond CR (mm)	Upper harne's loads (KN)	Lap sect'n loads (KN)	Crotch strap loads (KN)
3124 Baseline	ISOFIX 4 point pivoting (0 deg)	Pivot buck	Baseline	P3	N/A	39	28	16		1.61	0.57	0.95
3127 (1.00mm) shear EA	ISOFIX 4 point pivoting (0 deg)	Pivot buck	With Paton shear type (1mm thick) energy abs	P3	N/A	51	36	4		1.84	0.74	1.82

Test	Friction EA in harness	10°	P3		Head res	Chest res	Chest z tension	Chest z comp	Excursion beyond CR	Upper harne's loads	Lap sect'n loads	Crotch strap loads
	CRS description	Set up on sled	CRS factors	Man	g	g	pos'g'	neg'g'	mm	KN	KN	KN
3255 B'line	ISOFIX 4 point pivoting (10 deg) with Bob Sing'n friction energy abs	Pivot buck	Pad tight No energy abs activation, hence baseline	P3	70	49	32	11		0.94	1.45	1.68
3260 Friction EA	ISOFIX 4 point pivoting (10 deg) with Bob Sing'n friction energy abs	Pivot buck	Loose pad 50mm stroke on absorber	P3	60	37	27	10		0.92	1.02	1.47

Test	Mk2 Polymer EA in harness 30°		P3		Head res	Chest res	Chest z tension	Chest z comp	Excursion beyond CR	Upper harne's loads	Lap sect'n loads	Crotch strap loads
	CRS description	Set up on sled	CRS factors	Man	g	g	pos'g'	neg'g'	mm	KN	KN	KN
3131 B'line	ISOFIX 4 point pivoting (30 deg)	Pivot buck	Reinforced shell, Baseline	P3	N/A	44	35	15		0.98	0.74	0.96
3266 B'line	ISOFIX 4 point pivoting (30 deg)	Pivot buck	No energy abs Repeat of T3131, baseline	P3	60	39	33	12		0.83	0.96	0.85
3304 B'line	ISOFIX 4 point pivoting (30 deg) with the Witherington wonder (9mm pitch) polymer energy abs	Pivot buck	No energy abs activation	P3	63	46	31	18	326	0.99	0.82	0.88
3303 Polymer EA	ISOFIX 4 point pivoting (30 deg) with the Witherington Wonder Mk2 (holes getting closer together) polymer energy abs	Pivot buck	Worked from hole 3 to hole 9 (not full travel) 40mm stroke	P3	69	43	29	13	357	0.85	0.96	0.61

Test	Shear type EA in harness	30°	P3		Head res	Chest res	Chest z tension	Chest z com'p	Excursion beyond CR	Upper harne's loads	Lap sect'n loads	Crotch strap loads
	CRS description	Set up on sled	CRS factors	Man	g	g	pos'g'	neg'g'	mm	KN	KN	KN
3131 B'line	ISOFIX 4 point pivoting (30 deg)	Pivot buck	Reinforced shell, Baseline	P3	N/A	44	35	15		0.98	0.74	0.96
3266 B'line	ISOFIX 4 point pivoting (30 deg)	Pivot buck	No energy abs Repeat of T3131, baseline	P3	60	39	33	12		0.83	0.96	0.85
3302 (1.00mm) shear EA	ISOFIX 4 point pivoting (30 deg) with the Paton shear type (1mm thick) steel energy abs	Pivot buck	Approx 25mm stroke acheived	P3	62	32	21	11	364	0.85	0.83	0.58
3306 (0.75mm) shear EA	ISOFIX 4 point pivoting (30 deg) with the Paton shear type (0.75mm thick 'Sierra') steel energy abs	Pivot buck	Approx 40mm stroke acheived	P3	70	38	31	11	376	0.76	1.00	0.55

Test	Corrugated type EA in harness	30°	P3	Head res	Chest res	Chest z tension	Chest z com'p	Excursion beyond CR	Upper harne's loads	Lap sect'n loads	Crotch strap loads

	CRS description	Set up on sled	CRS factors	Man	g	g	pos'g'	neg'g'	mm	KN	KN	KN
3131 B'line	ISOFIX 4 point pivoting (30 deg)	Pivot buck	Reinforced shell, Baseline	P3	N/A	44	35	15		0.98	0.74	0.96
3266 B'line	ISOFIX 4 point pivoting (30 deg)	Pivot buck	No energy abs Repeat of T3131, baseline	P3	60	39	33	12		0.83	0.96	0.85
3308 No actv'n	repeat of 3305 with shear pin 5mm dia	Pivot buck	No activation	P3	63	45	31	15	339	0.93	0.83	0.74
3309 No actv'n	repeat of 3305 with shear pin 5mm dia with 1mm dia hole in it	Pivot buck	No activation	P3	71	43	28	14	345	1.05	0.82	0.83
3305 (1.00mm) cor't EA	ISOFIX 4 point pivoting (30 deg) with the Paton corrugated type (1mm thick) steel energy abs	Pivot buck	Approx 30mm stroke aceived	P3	71	37	29	10	364	0.78	0.95	0.61
3307 (0.75mm) cor't EA	ISOFIX 4 point pivoting (30 deg) with the Paton corrugated type (0.75mm thick 'Sierra') steel energy abs	Pivot buck	Approx 100mm stroke acheived	P3	78 noise	38 noise	25	12	414	1.05	0.89	0.61
3310 (1.00mm) cor't EA+pin	repeat of 3305 with shear pin 5mm dia with 2mm dia hole in it	Pivot buck	25mm activation	P3	62	43	34	16	357	0.81	0.91	0.59

Test	Corrugated type EA with shear pin in harness	30°	P3		Head res	Chest res	Chest z tension	Chest z comp	Excursion beyond CR	Upper harne's loads infront of shell	Lap sect'n loads	Crotch strap loads
	CRS description	Set up on sled	CRS factors	Man	g	g	pos'g'	neg'g'	mm	KN	KN	KN
3404 B'line	Base line for the following ISOFIX 4 point pivoting (30 deg) with the Paton Mk1 rectangular corrugated type (1mm thick) steel energy abs	Pivot buck	No activation bolted up, baseline	P3	68	44	34	19	330	1.46	1.19	N/R
3405 B'line	ISOFIX 4 point pivoting (30 deg) with the Paton Mk1 rectangular corrugated type (1mm thick) steel energy abs 5mm delrin 2mm hole	Pivot buck	No activation (Should have been) ie another baseline test	P3	76 noise	45 noise	29	19	316	1.56	1.11	N/R
3406	ISOFIX 4 point pivoting (30 deg) with the Paton Mk1 rectangularcorugated type (1mm thick) steel energy abs 5mm delrin 3mm hole	Pivot buck	Activation 30mm stroke	P3	72	39	33	19	358	1.44	0.90	N/R
3407	ISOFIX 4 point pivoting (30 deg) with the Paton Mk1 rectangular corrugated type (1mm thick) steel energy abs 5mm delrin 3mm hole	Pivot buck	Activation 35mm stroke	P3	71	39	30	18	372	1.65	0.87	N/R
3408	ISOFIX 4 point pivoting (30 deg) with the Paton tapered corrugated type (1mm thick) steel energy abs 5mm delrin 3mm hole Still with slotted firing hole as previous	Pivot buck	Activation 44mm stroke	P3	78 noise	41 noise	34	20	393	1.62	0.92	N/R
3409	ISOFIX 4 point pivoting (30 deg) with the Paton tapered corrugated type (1mm thick) steel energy abs 5mm delrin 3mm hole Still with slotted firing hole as previous	Pivot buck	Activation 45mm stroke	P3	69	42	32	17	393	1.88	0.86	N/R

3410	ISOFIX 4 point pivoting (30 deg) with the Paton tapered corrugated type (1mm thick) steel energy abs 5mm delrin 3mm holewith plastic hindge type shear pin	Pivot buck	Activation 48mm stroke	P3	69	41	23	15	393	1.79	0.82	N/R
3411	ISOFIX 4 point pivoting (30 deg) with the Paton rectangular corrugated type (1mm thick) steel energy abs 5mm delrin 3.5mm hole with plastic hindge type shear pin	Pivot buck	Activation 45mm stroke	P3	61 noise	40 noise	25	17	358	1.71	0.70	N/R
3412	ISOFIX 4 point pivoting (30 deg) with the Paton rectangular corrugated type (2mm thick, ie two spot welded together) steel energy abs 5mm delrin 3.5mm hole with plastic hindge type shear pin	Pivot buck	Activation 20mm stroke	P3	65 noise	42 noise	31	15	351	1.61	0.88	N/R

Test	Corrugated type EA in harness (tight harness)	30°	P3		Head res	Chest res	Chest z tension	Chest z comp	Excursion beyond CR	Upper harne's loads infront of shell	Lap sect'n loads	Crotch strap loads
	CRS description	Set up on sled	CRS factors	Man	g	g	pos'g'	neg'g'	mm	KN	KN	KN
3414 B'line	ISOFIX 4 point pivoting (30 deg) with standard harness but fitted tight ie no 1" block down back of manikin (No energy absorber) ie Baseline for next test	Pivot buck	Standard R44 test but with No 1" block ie tight harness	P3	61	37	32	12	316	1.51	1.22	N/R
3415 (1.00mm) corg't EA	ISOFIX 4 point pivoting (30 deg) with standard harness but fitted tight ie no 1" block down back of manikin (With rectangular corg't 1mm thick energy absorber)	Pivot buck	Activation 50mm stroke	P3	65	36	28	12	337	1.48	1.16	N/R

Test	Std CRS VS ISOFIX / CANFIX	30°	P3		Head res	Chest res	Chest z tension	Chest z comp	Excu'n beyond CR	Peak Neck 'x' shear	30 ms Neck 'x' shear	Peak Neck 'z' tension	30 ms Neck 'z' tension	Mom't Mb @ C'line / 10
	CRS description	Set up on sled	CRS factors	Man	g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3580 STD No MPads	Std freeway L&D without majic pads	Ste ECE R44		P3	65	47	20	14	643	1.37	0.69	2.15	1.06	2.77
3578 STD with Mpad	Std freeway L&D with majic pads	Ste ECE R44		P3	62	50	16	15	602	1.53	0.73	2.20	1.20	3.30
3607 4 point with MPad	Repeat of 3604 Pivot buck with low friction back bar But with magic pads (30o) No EA	Pivot buck	13.94 m/s	P3	56	49	34	17	364	1.59	0.85	2.15	0.97	3.18
3582 CAUSFIX with MPad	Canfix freeway with magic pads, std 1.5" TT (30°)	Canfix		P3	62	48	18	15	430	1.73	0.76	2.22	1.25	3.38

Test	CANFIX with TT EA	30°	P3		Head res	Chest res	Chest z tension	Chest z com'p	Excu'n beyond CR	Peak Neck 'x' shear	30 ms Neck 'x' shear	Peak Neck 'z' tension	30 ms Neck 'z' tension	Mom't Mb @ C'line / 10
	CRS description	**Set up on sled**	**CRS factors**	**Man**	g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3582 Baseline	Canfix freeway with magic pads, std 1.5" TT (30°)	Canfix		P3	62	48	18	15	430	1.73	0.76	2.22	1.25	3.38
3583 1 thickness EA	repeat of 3582, Canfix freeway with magic pads, plus corrugated energy absorber (single thickness) in Top Tether	Canfix	13.92 m/s	P3	50	42	17	15	466	1.53	0.80	2.01	0.97	2.86
3584 2 thichness EA	as 3583 but duuble thickness energy absorber	Canfix	13.80 m/s	P3	45	37	14	9	473	1.25	0.74	1.66	0.96	2.30

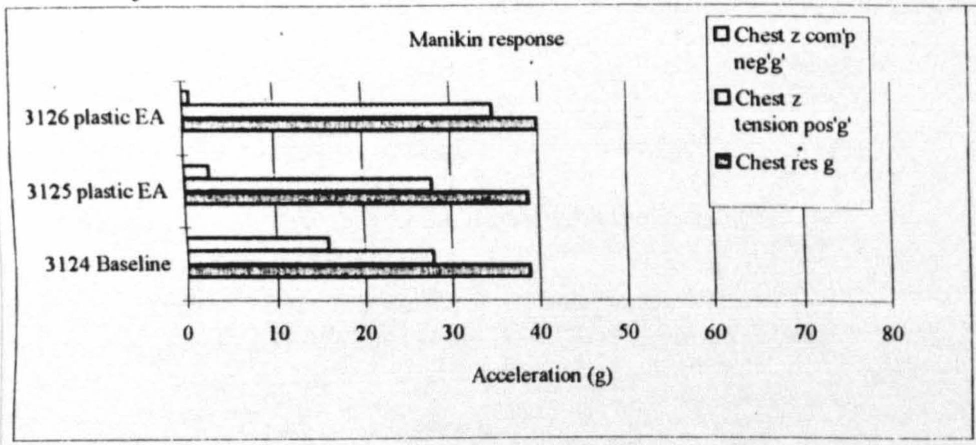
Test	4 point isofix with harness EA 30° P3				Head res	Chest res	Chest z tension	Chest z comp	Excu'n beyond CR	Peak Neck 'x' shear	30 ms Neck 'x' shear	Peak Neck 'z' tension	30 ms Neck 'z' tension	Mom't Mb @ C'line / 10
	CRS description	**Set up on sled**	**CRS factors**	**Man**	g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3607 4point with MPad	Repeat of 3604 Pivot buck with low friction back bar But with magic pads (30o) No EA	Pivot buck	13.94 m/s	P3	56	49	34	17	364	1.59	0.85	2.15	0.97	3.18
3604 4point No MPad	Repeat of 3593 Pivot buck with low friction back bar No magic pads (30o)	Pivot buck	14.02 m/s No video U/S	P3	63	43	31	14	408	1.68	0.89	2.22	0.96	3.41
4point No MPad 1xTT EA	Repeat of 3604 Pivot buck with low friction back bar No magic pads (30o) With the addition of single thickness 3 corrigation EA in harness yoke with shear pin	Pivot buck	13.86 m/s EA activation 37mm	P3	76	44	37	13	376	1.71	0.89	2.30	0.88	3.27
4point No MPad 2xTT EA	Repeat of 3605 Pivot buck with low friction back bar No magic pads (30o) With the addition of double thickness 3 corrigation EA in harness yoke with shear pin	Pivot buck	14.07 m/s EA activation 25mm	P3	69	40	32	14	376	1.58	0.77	2.11	1.05	3.00

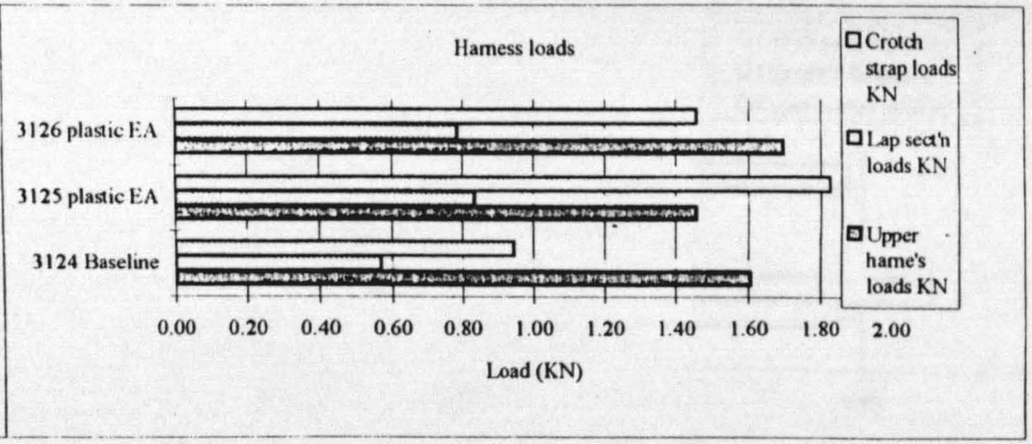
Test	Std CRS VS ISOFIX / CANFIX	30°	P3/4		Head res	Chest res	Chest z tension	Chest z com'p	Excu'n beyond CR	Peak Neck 'x' shear	30 ms Neck 'x' shear	Peak Neck 'z' tension	30 ms Neck 'z' tension	Mom't Mb @ C'line / 10
	CRS description	**Set up on sled**	**CRS factors**	**Man**	g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3619 Std CRS with MPad	Lap & Diagn'l with majic pads	Std freeway		P3/4	66	52	11	12	521	1.28	0.81	1.81	1.16	2.43
3620 Std CRS without MPad	Lap &Diagn'l without majic pads	Std freeway		P3/4	60	48	9	11	521	1.13	0.80	1.48	1.11	2.08
3608 4Point isofix No MPad	Repeat of 3604 Pivot buck with low friction back bar No magic pads (30o) No EA P3/4 manikin	Pivot buck	14.06 m/s	P3/4	61	42	19	16	364	1.04	0.63	1.52	0.78	2.11
3625 Canfix with MPad	Canfix std with magic pads 1.5"tt	Canfix		P3/4	47	40	12	17	332	1.05	0.71	1.45	0.84	1.9
3626 Canfix No MPad	Canfix std with No magic pads 1.5"tt P3/4 manikin	Canfix	13.52 m/s baseline	P3/4	46	42	19	13	326	1.09	0.70	1.51	0.93	1.92

Test	CANFIX with EA	30°	P3/4		Head res	Chest res	Chest z tension	Chest z com'p	Excu'n beyond CR	Peak Neck 'x' shear	30 ms Neck 'x' shear	Peak Neck 'z' tension	30 ms Neck 'z' tension	Mom't Mb @ C'line / 10
	CRS description	**Set up on sled**	**CRS factors**	**Man**	g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3630 steel strip TT NO MPad	**As 3627 but with solid steel strip replacing EA in TT NO MPad**	**Canfix**	**baseline**	**P3/4**	**48**	**46**	**26**	**11**	**333**	**1.24**	**0.65**	**1.70**	**0.83**	**2.40**
3626 B'line NO MPad	**Canfix std with No magic pads 1.5"tt**	**Canfix**	**13.52 m/s baseline**	**P3/4**	**46**	**42**	**19**	**13**	**332**	**1.09**	**0.70**	**1.51**	**0.93**	**1.92**
3627 1x Corg't TT EA NO MPad	**As 3626 CANFIX no magic pads, but with 5 convolution EA single thickness (1mm thick) no pre trigger shear pin in TT**	**Canfix**	**13.35 m/s aprox 50mm activation**	**P3/4**	**48**	**43**	**16**	**15**	**333**	**1.15**	**0.70**	**1.52**	**0.98**	**2.20**
3628 2x Corg't TT EA NO MPad	**As 3627 but with double (two togther) EA mo MPad**	**Canfix**	**13.69 m/s aprox 33mm activation**	**P3/4**	**45**	**41**	**21**	**14**	**375**	**1.17**	**0.65**	**1.60**	**0.83**	**2.15**
3629 3x Corg't TT EA NO MPad	**As 3627 but with trebel thickness EA No MPad**	**Canfix**	**? m/s aprox 20mm activation**	**P3/4**	**50**	**42**	**14**	**11**	**354**	**1.15**	**0.70**	**1.43**	**1.00**	**2.10**

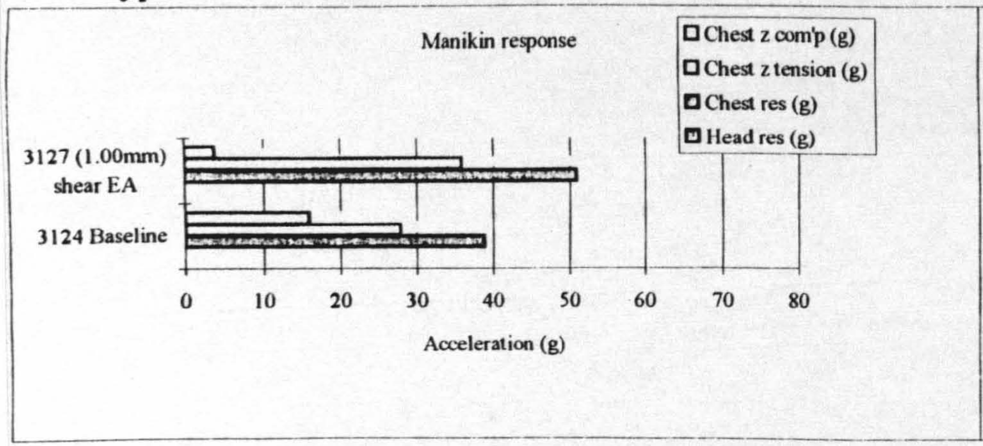
Test	CANFIX	30°	P3/4		Head res	Chest res	Chest z tension	Chest z comp	Excursion beyond CR	Peak Neck 'x' shear	30 ms Neck 'x' shear	Peak Neck 'z' tension	30 ms Neck 'z' tension	Mom't Mb @ C'line
	CRS description	Set up on sled	CRS factors	Man	g	g	pos'g'	neg'g'	mm	KN	KN	KN	KN	Nm
3652 Baseline	As 3640 but std 1.5" Webbing TT. ECE R44 03 harness set up ie 1" slack	Canfix	13.68m/s	P3/4	48	41	26	11	354	1.26	0.65	1.75	0.90	2.50
3640 steel strip	Canfix with NO ece r44 test seat cushion , no magic pads, stright steel strip top tether	Canfix	13.81m/s	P3/4	53	41	28	17	340	1.18	0.66	1.67	0.83	2.38
3651 2 thickness EA	Canfix with NO ece r44 test seat cushion, no magic pads, but with 5 convolution EA double thichness (1mm thick x 2) with pre trigger shear pin in TT dia 6mm, with dia 2.5mm Hole. ECE R44 03 harness set up ie 1" slack	Canfix	13.67m/s	P3/4	43	35	13	9	417	1.02	0.74	1.41	0.87	1.97

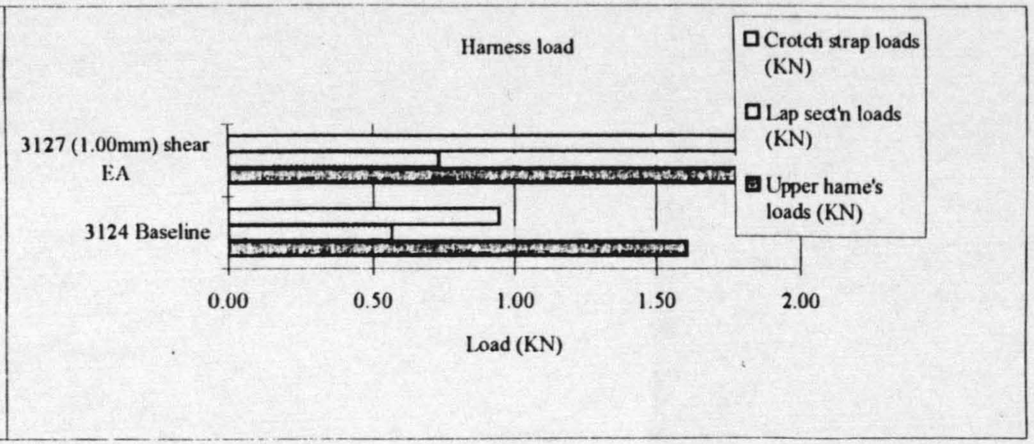
Mk1 Polymer EA in harness 0° P3



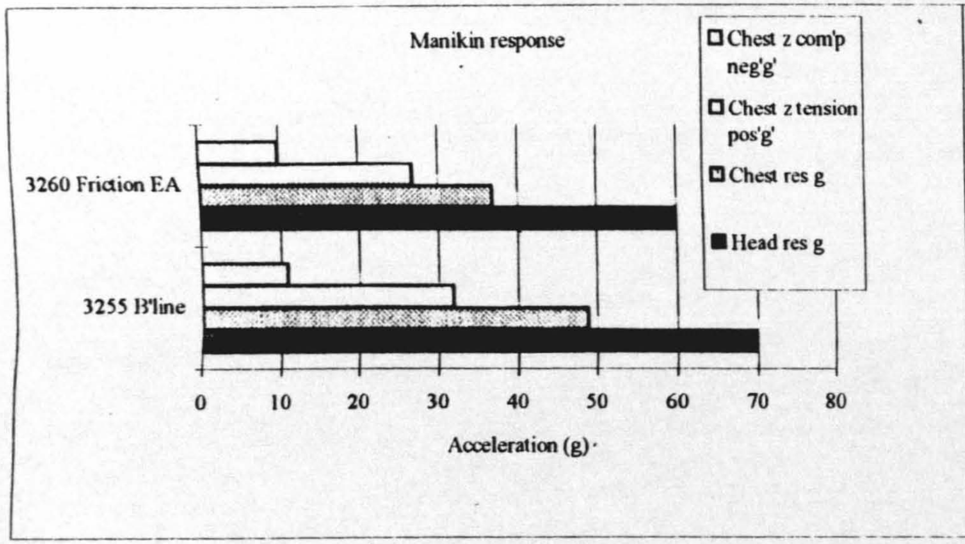


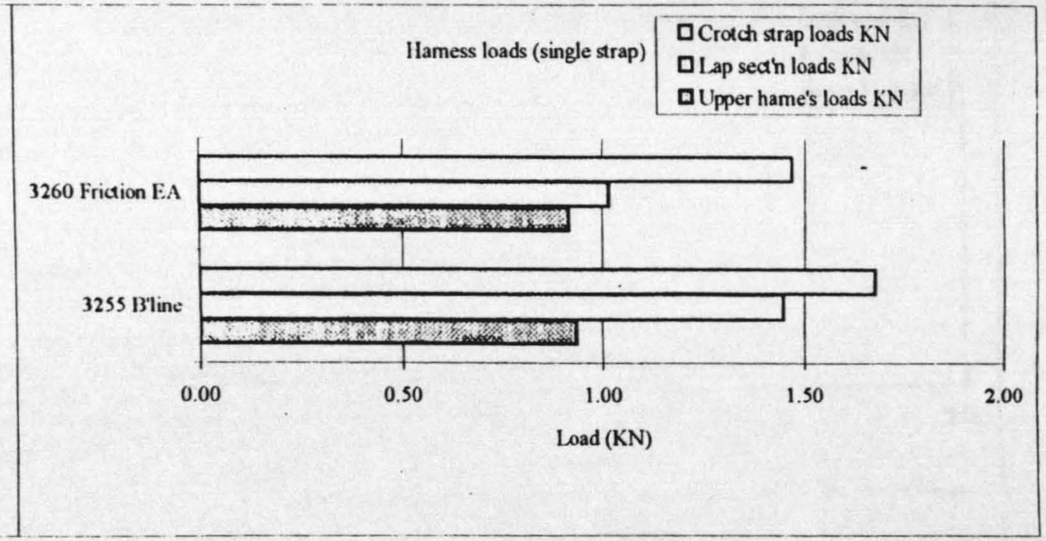
Shear type EA in harness 0° P3



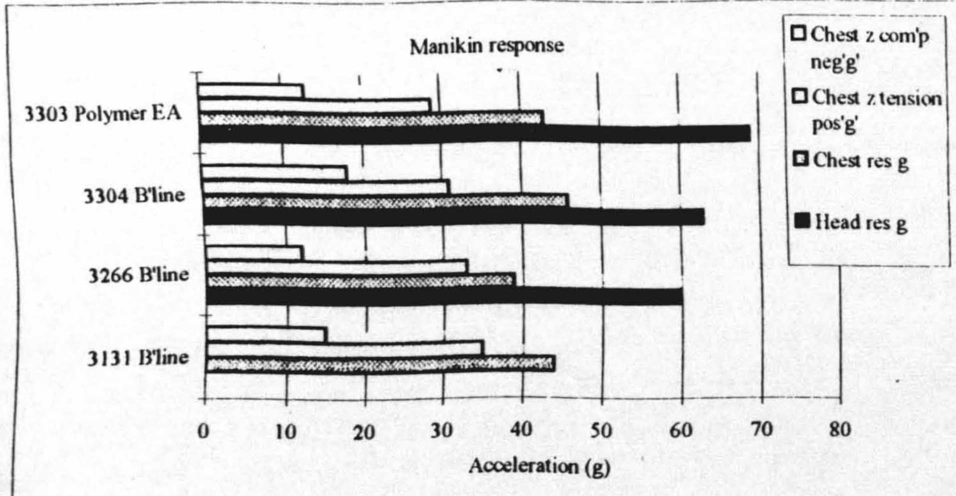


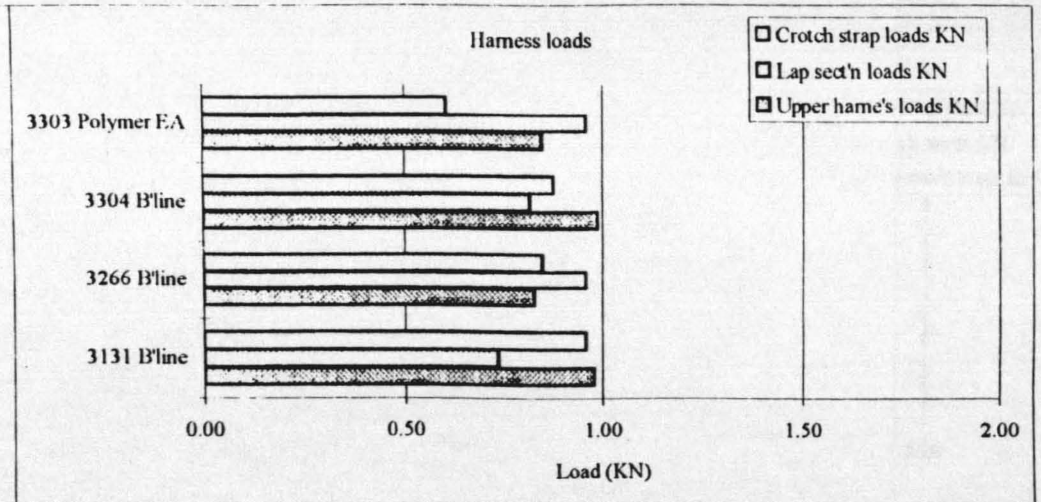
Friction EA in harness 10° P3

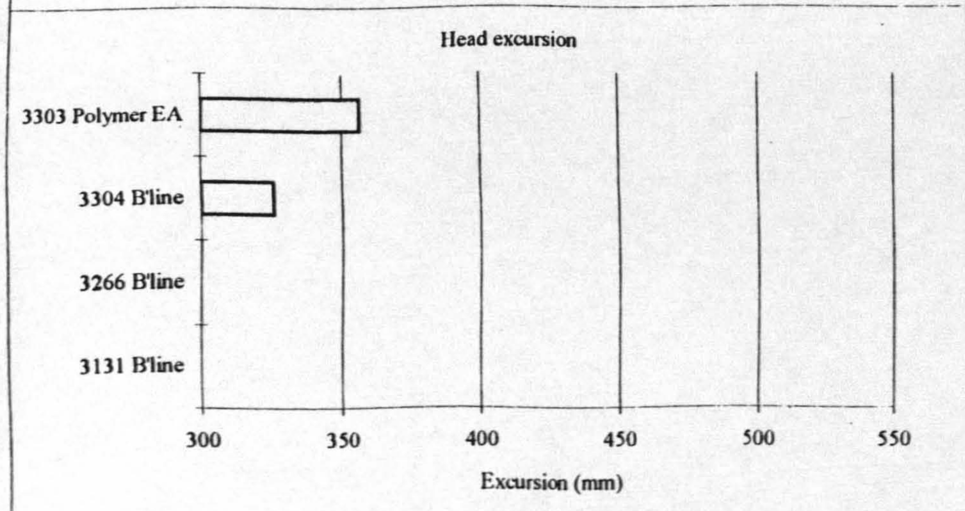




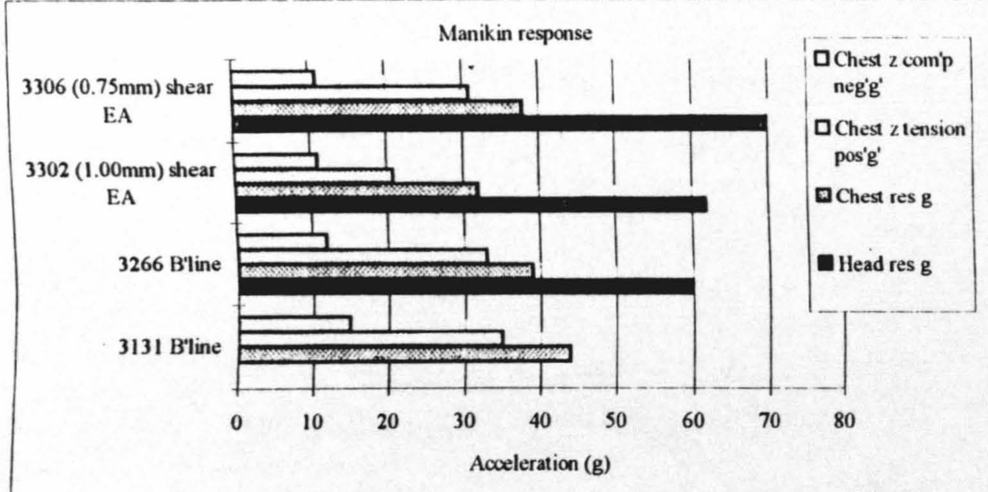
Mk2 Polymer EA in harness 30° P3

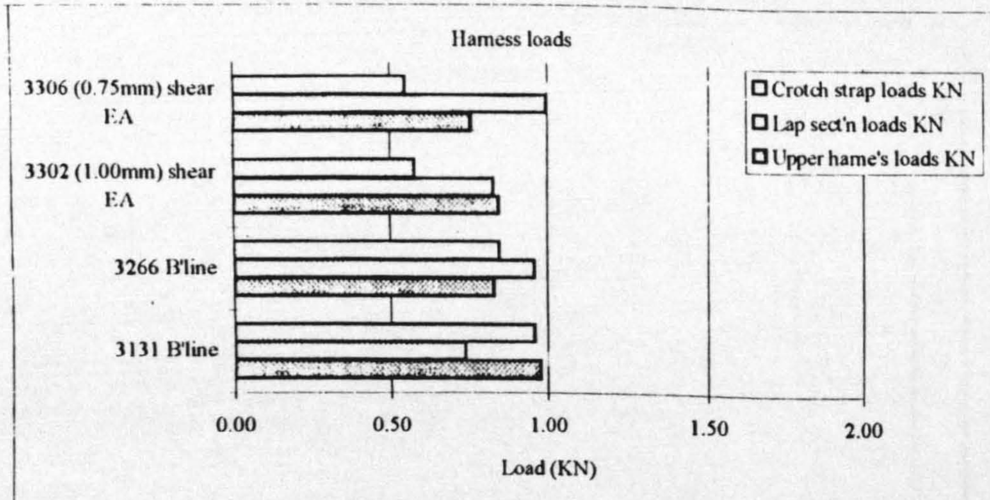


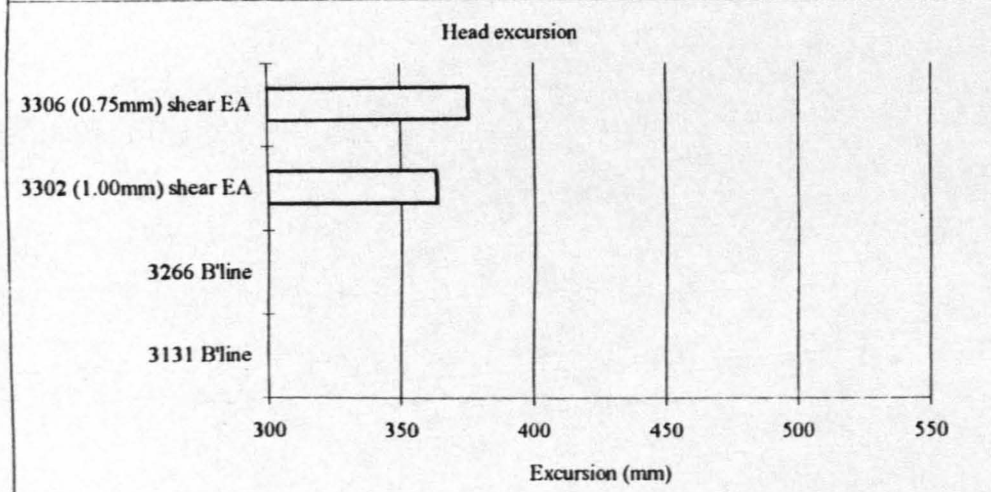




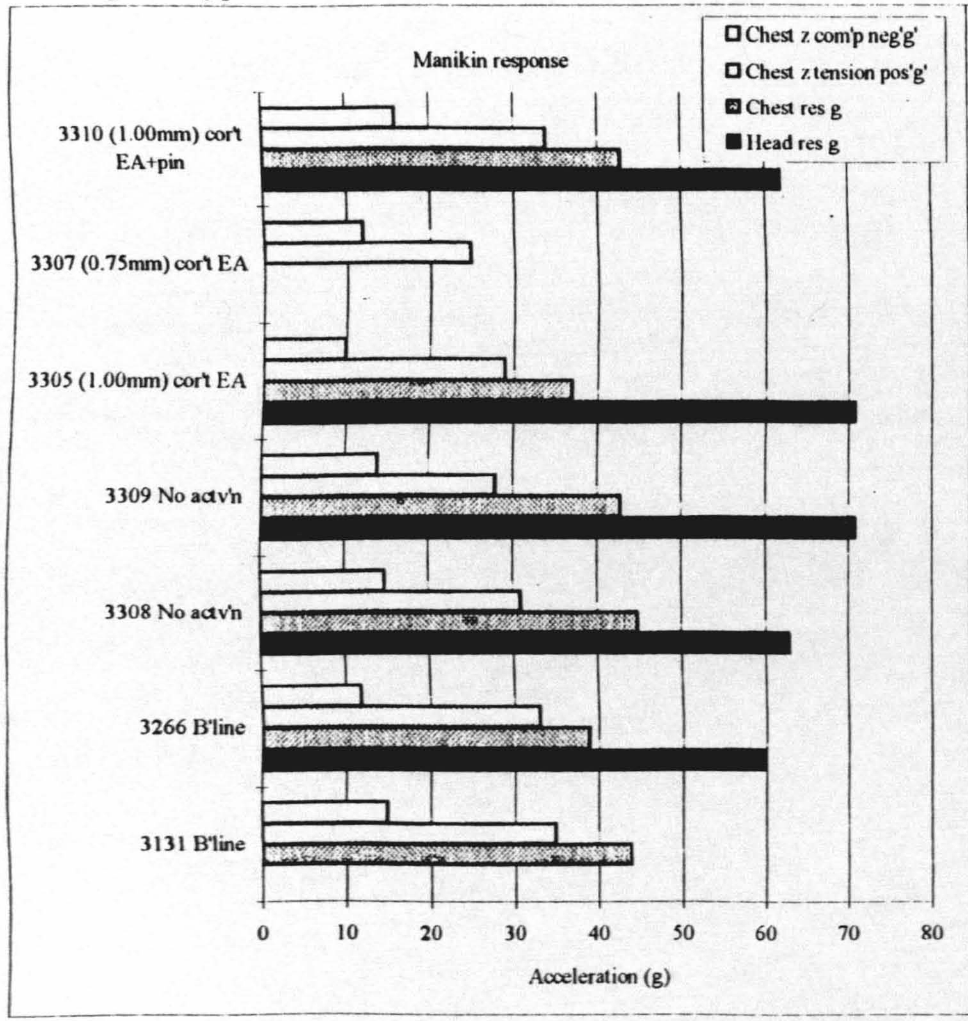
Shear type EA in harness 30° P3

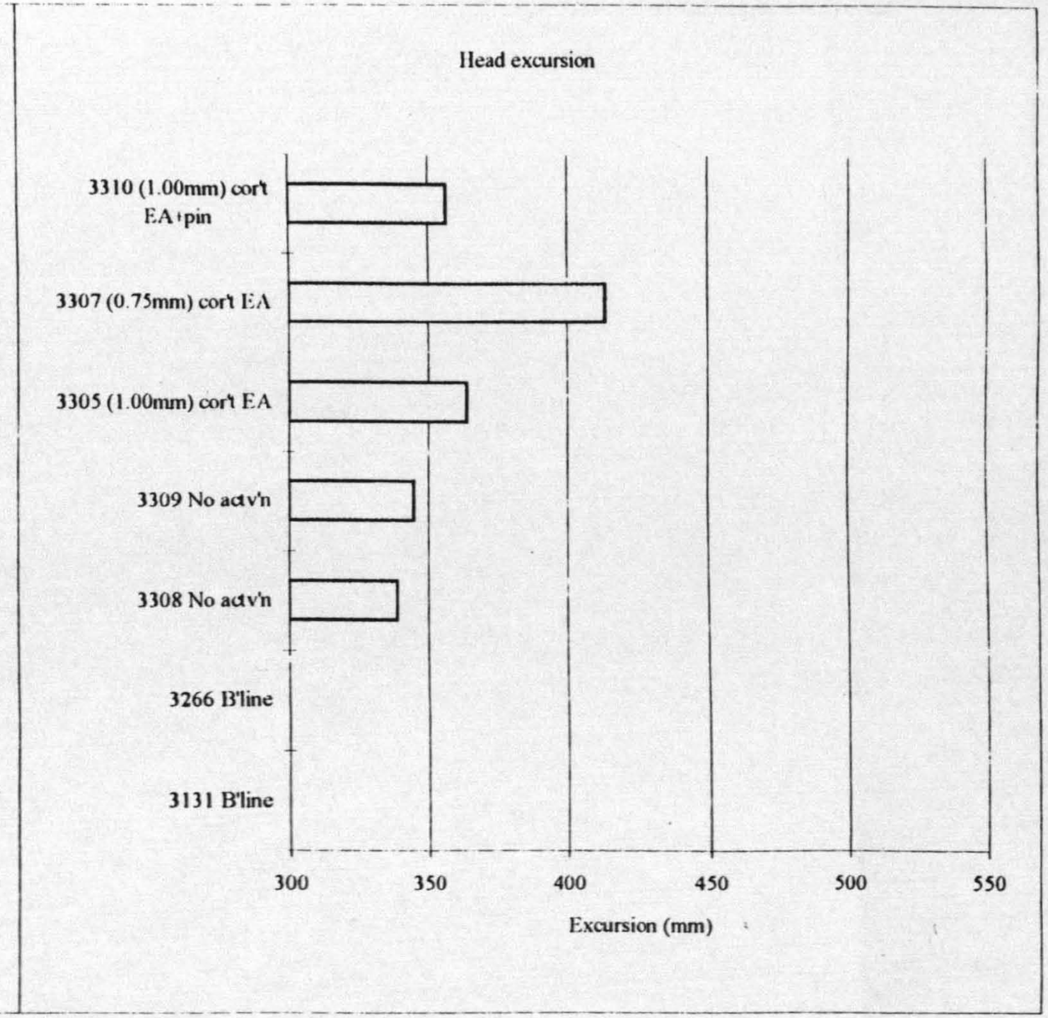






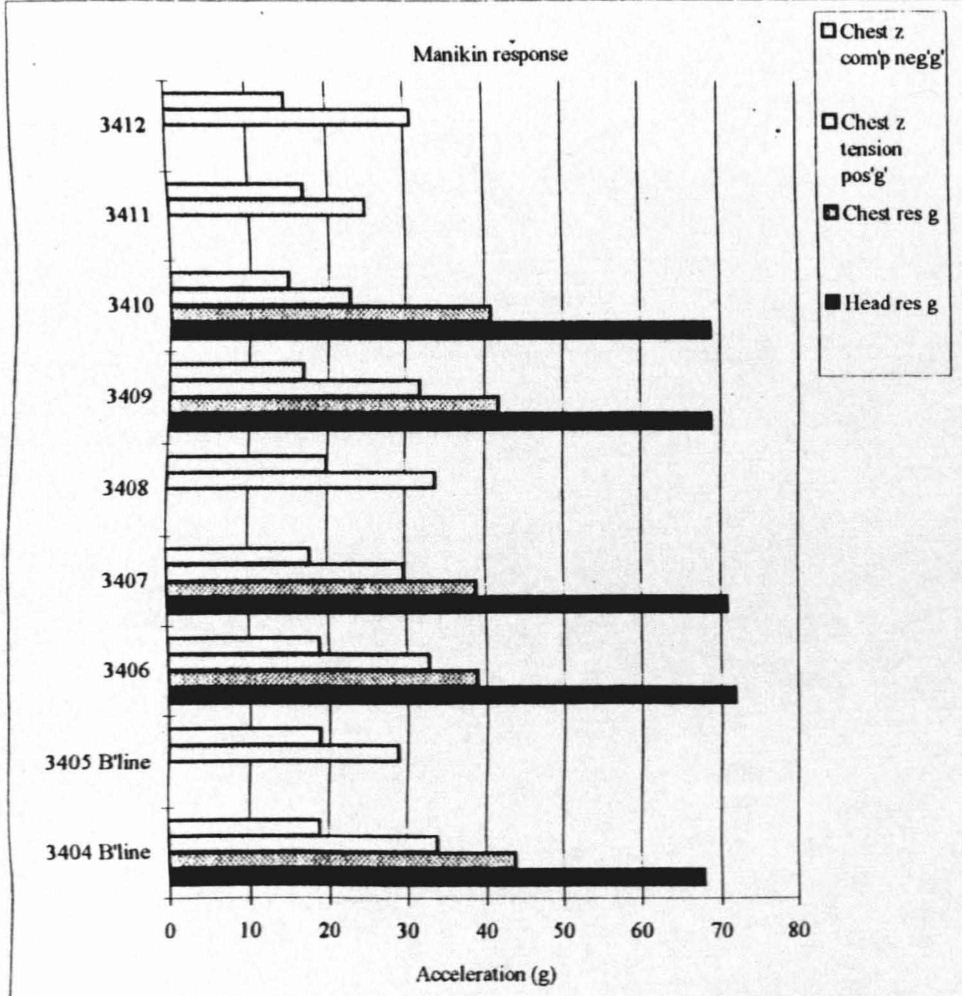
Corrugated type EA in harness 30° P3

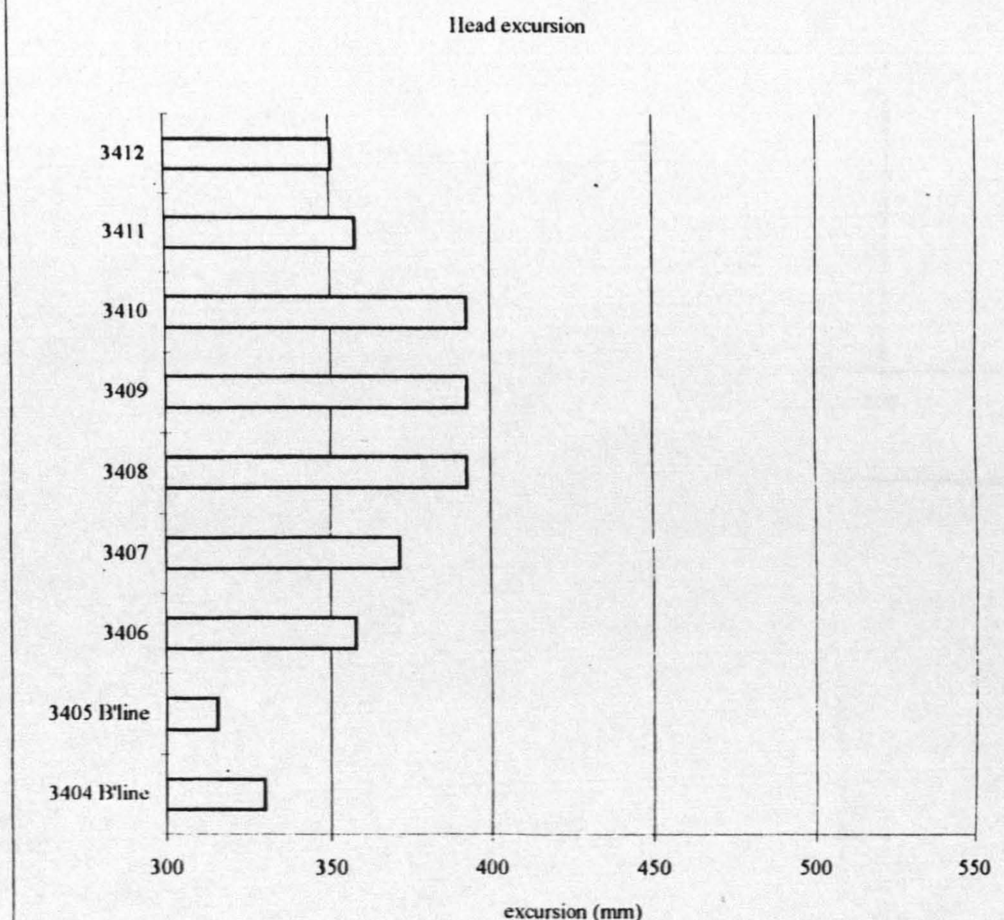




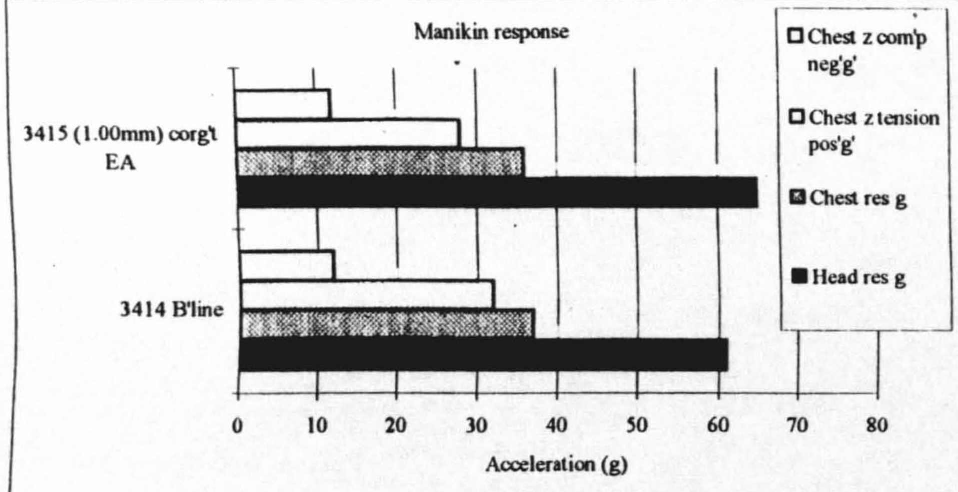
Corrugated type EA with shear pin in harness

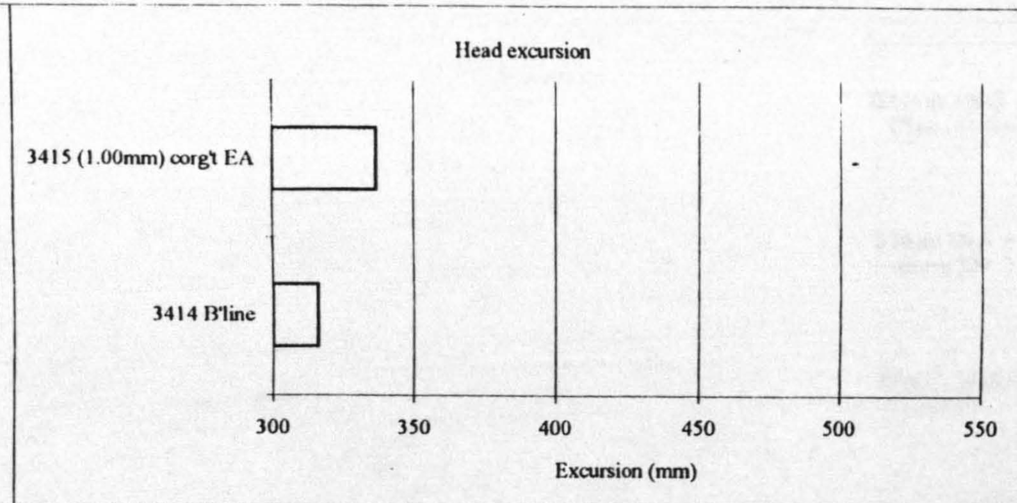
30° P3

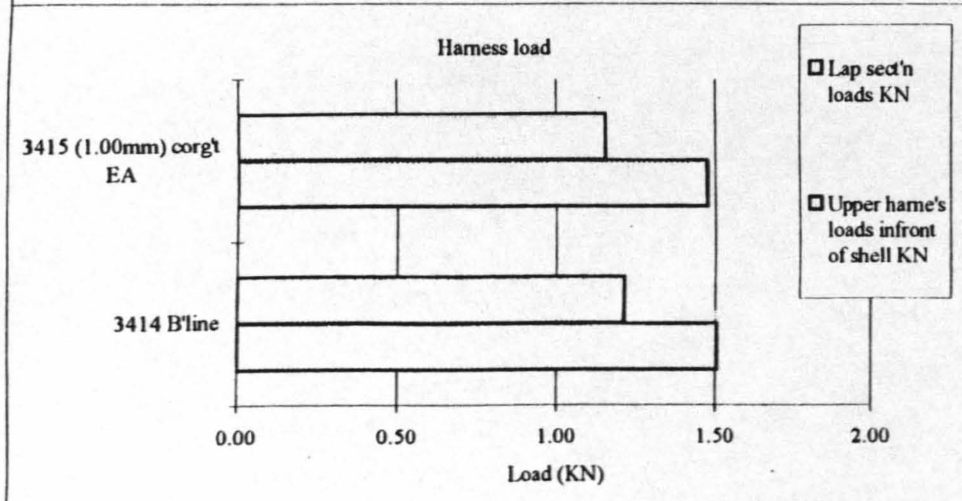




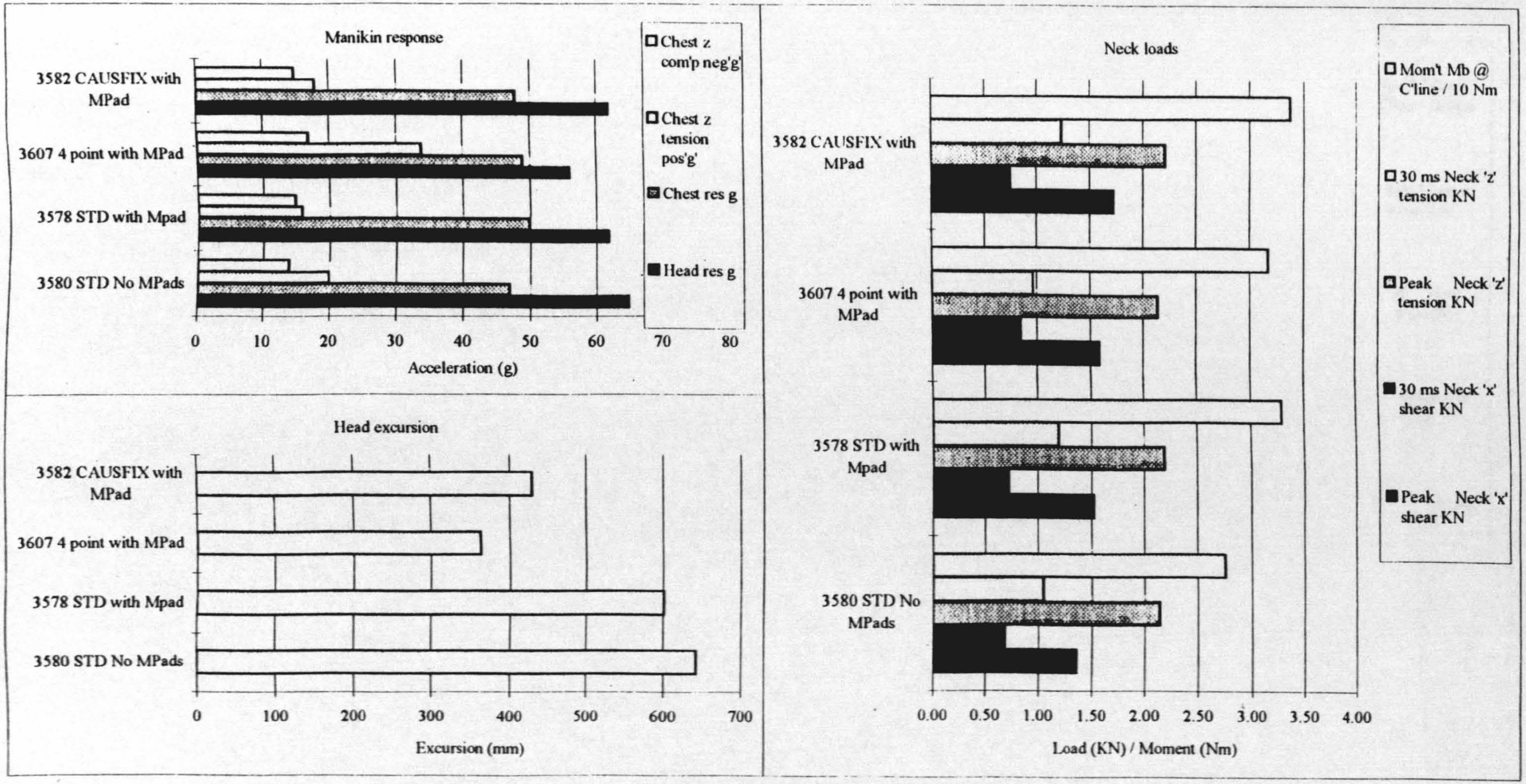
Corrugated type EA in harness (tight harness) 30° P3





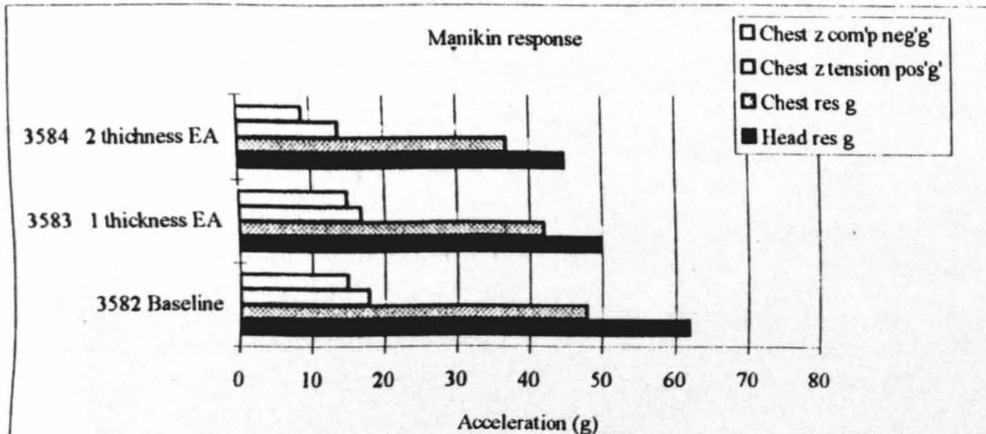


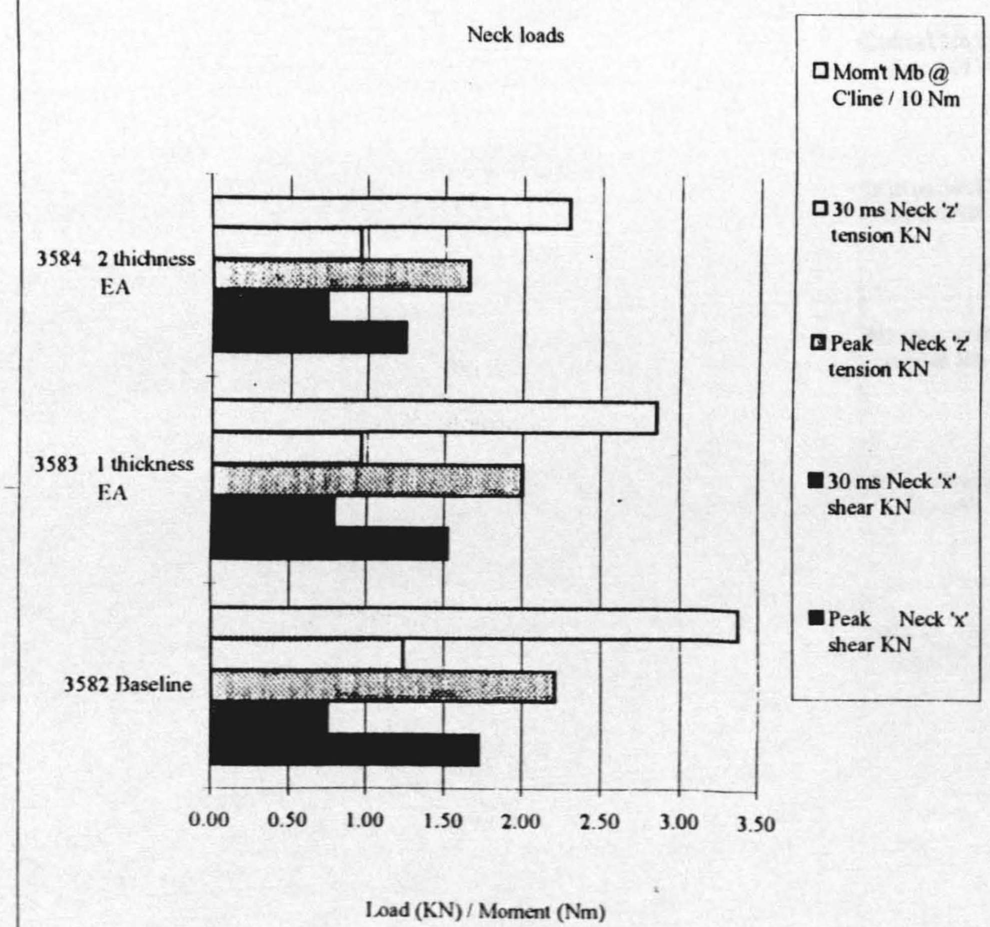
Std CRS VS ISOFIX / CANFIX 30° P3

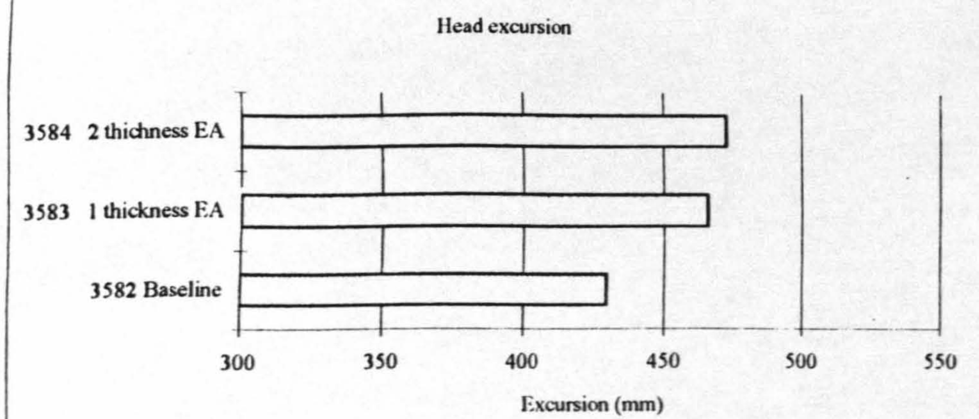


CANFIX with TT EA

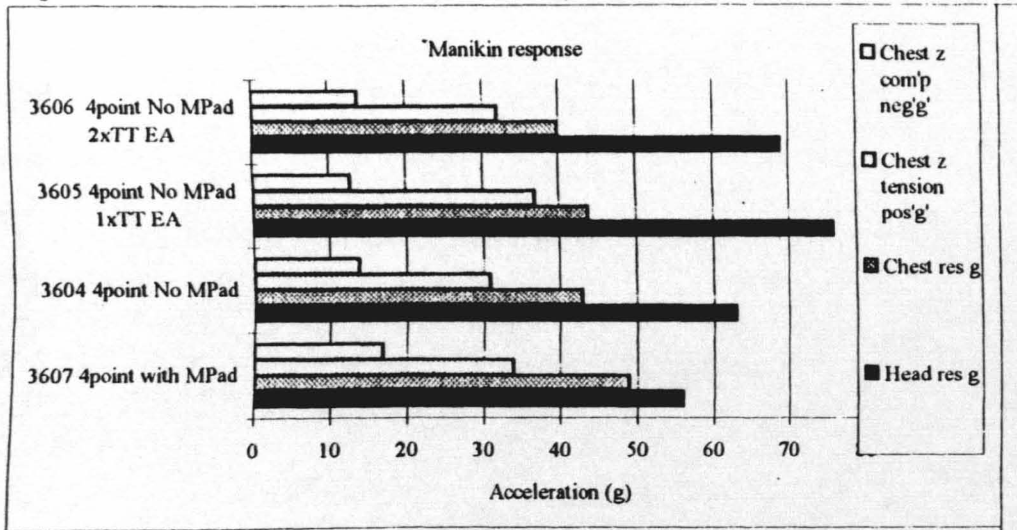
30° P3

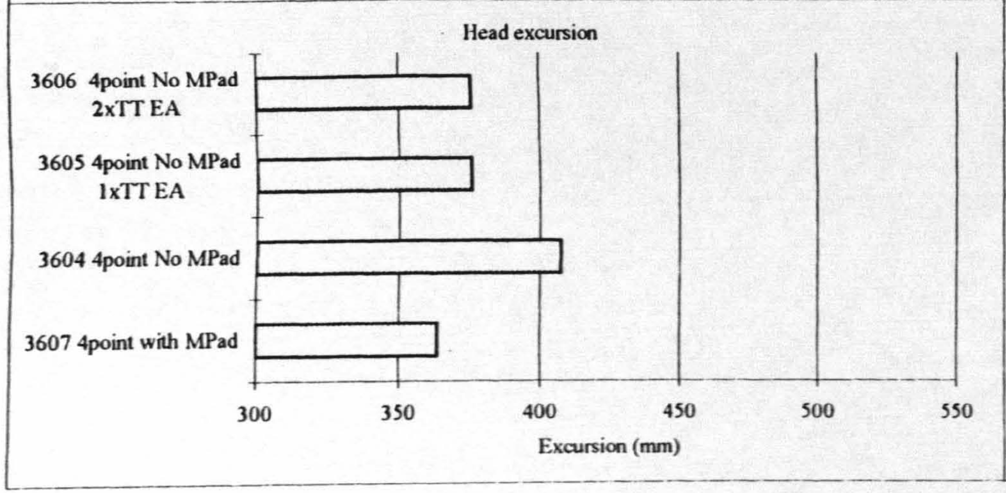


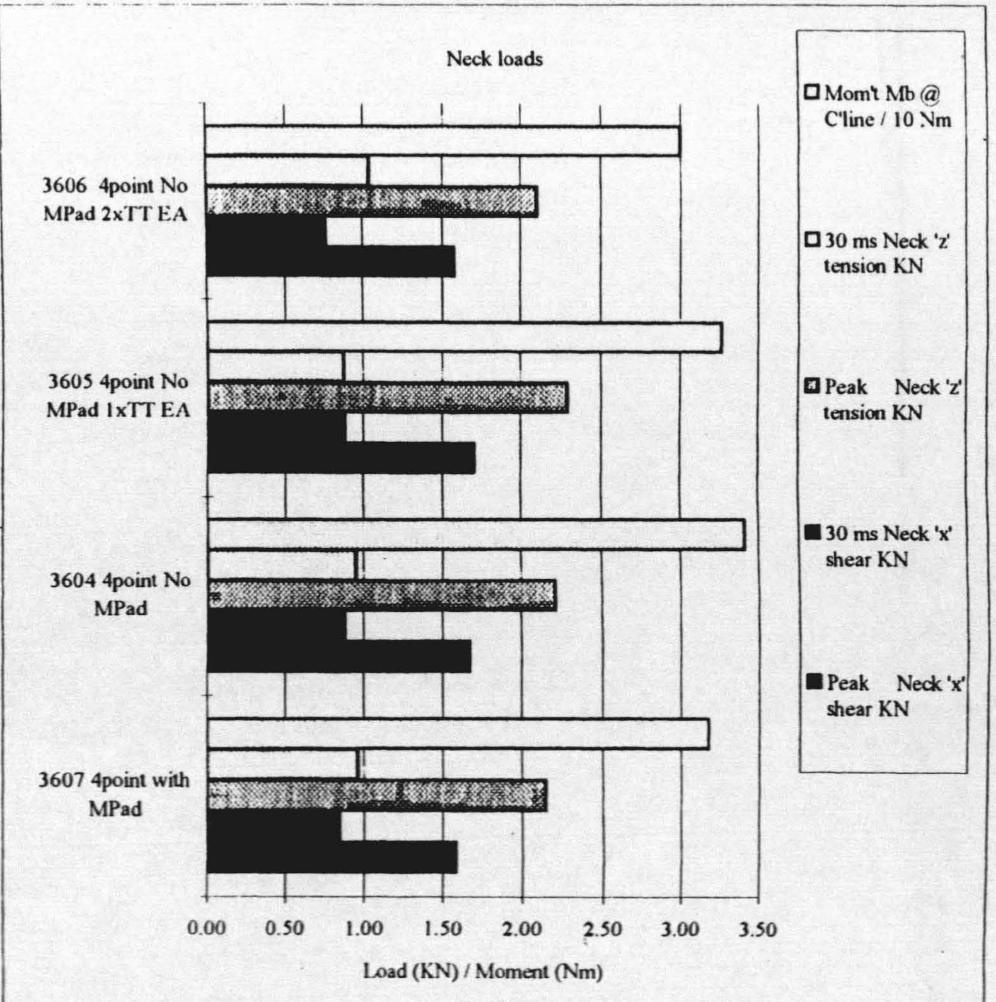


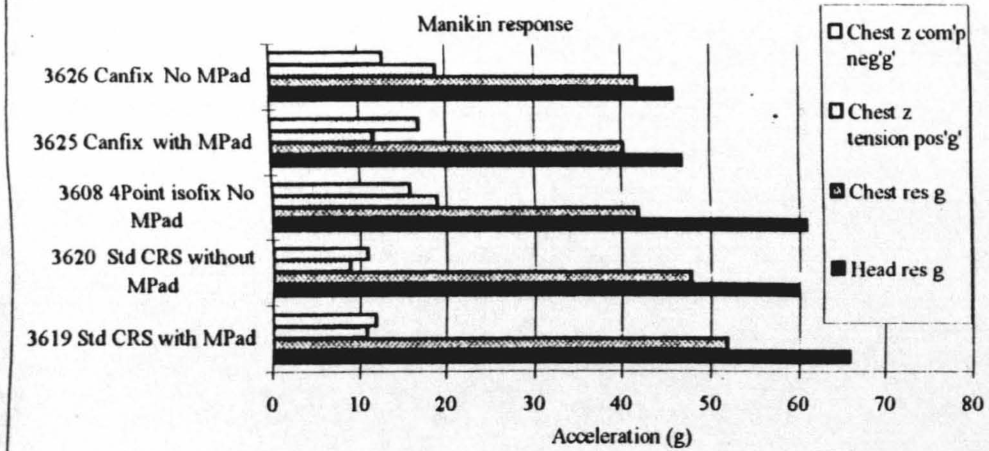


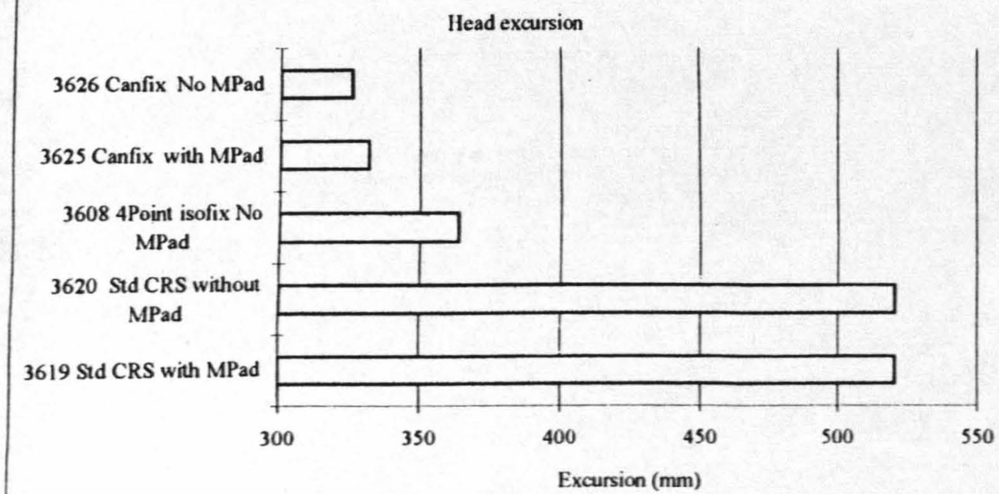
4 point isofix with harness EA 30° P3

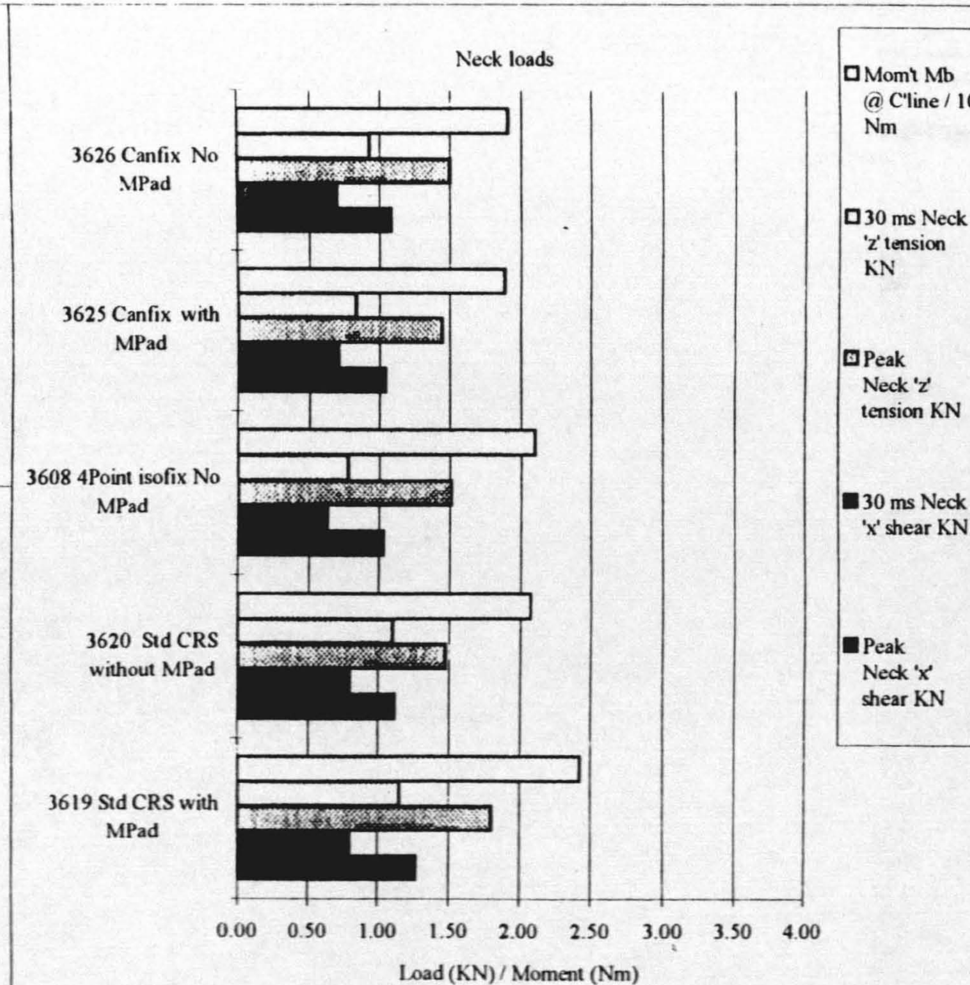




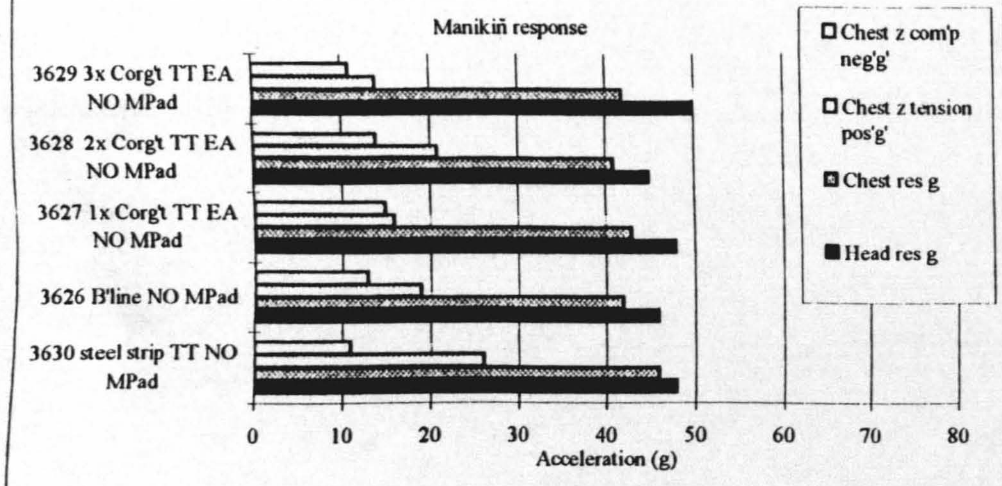


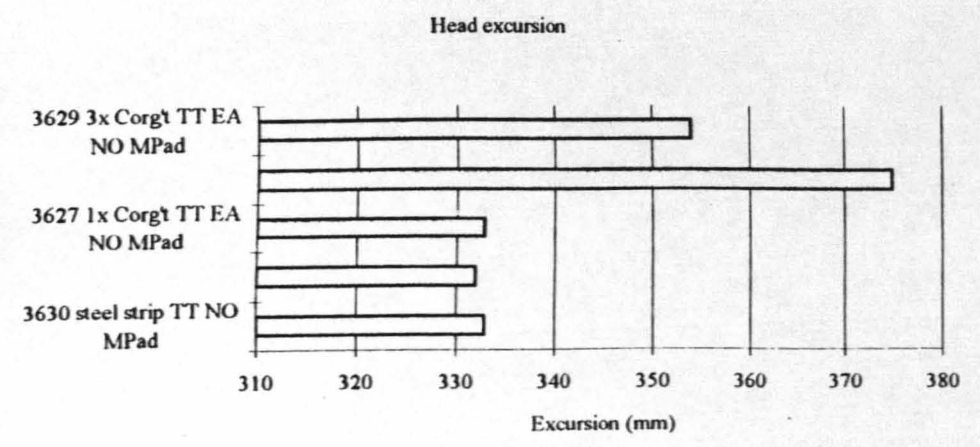

Manikin response
Chest z com'p neg'g'
Chest z tension pos'g'
Chest res g
Head res g
3626 Canfix No MPad
3625 Canfix with MPad
3608 4Point isofix No MPad
3620 Std CRS without MPad
3619 Std CRS with MPad
0
10
20
30
40
50
60
70
80
Acceleration (g)

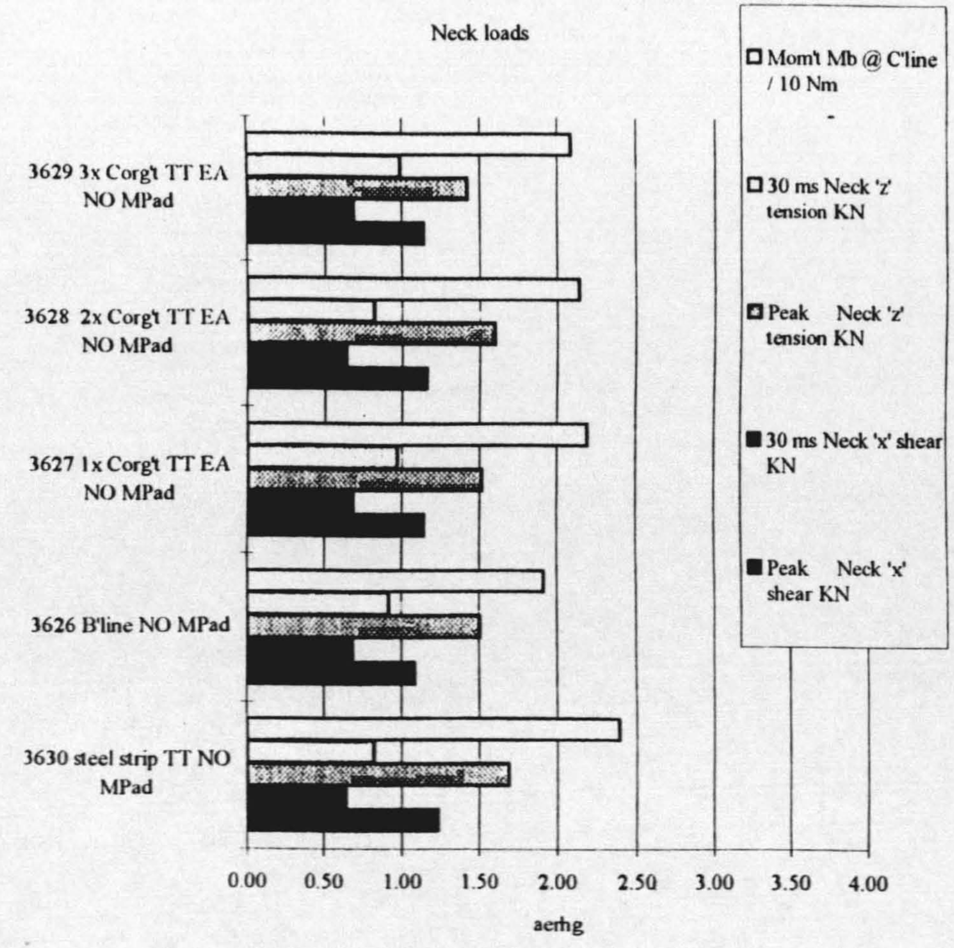

Head excursion
3626 Canfix No MPad
3625 Canfix with MPad
3608 4Point isofix No MPad
3620 Std CRS without MPad
3619 Std CRS with MPad
300
350
400
450
500
550
Excursion (mm)


Neck loads
Mom't Mb @ C'line / 10 Nm
30 ms Neck 'z' tension KN
Peak Neck 'z' tension KN
30 ms Neck 'x' shear KN
Peak Neck 'x' shear KN
3626 Canfix No MPad
3625 Canfix with MPad
3608 4Point isofix No MPad
3620 Std CRS without MPad
3619 Std CRS with MPad
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
Load (KN) / Moment (Nm)

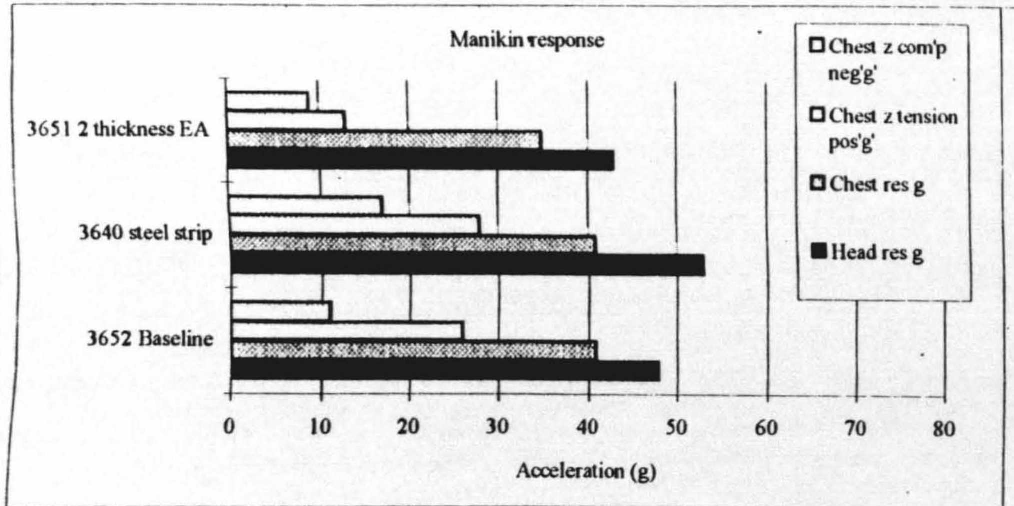
CANFIX with EA 30° P3/4

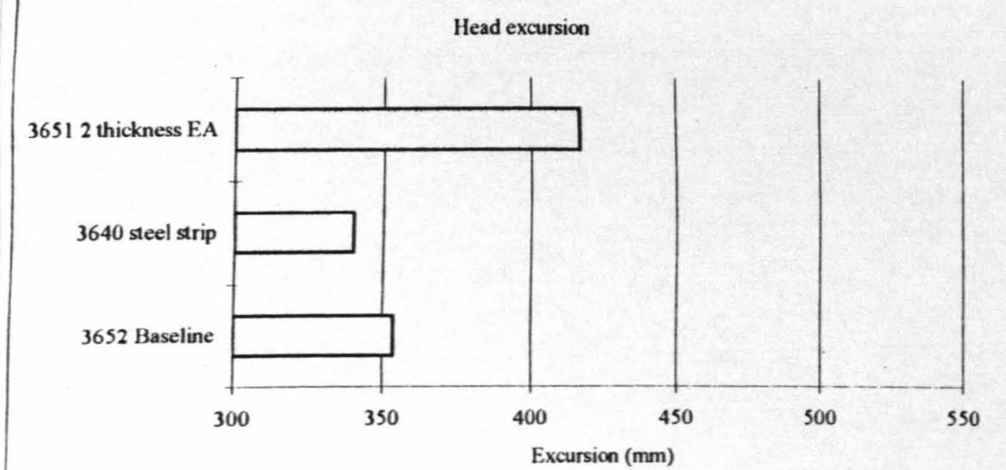


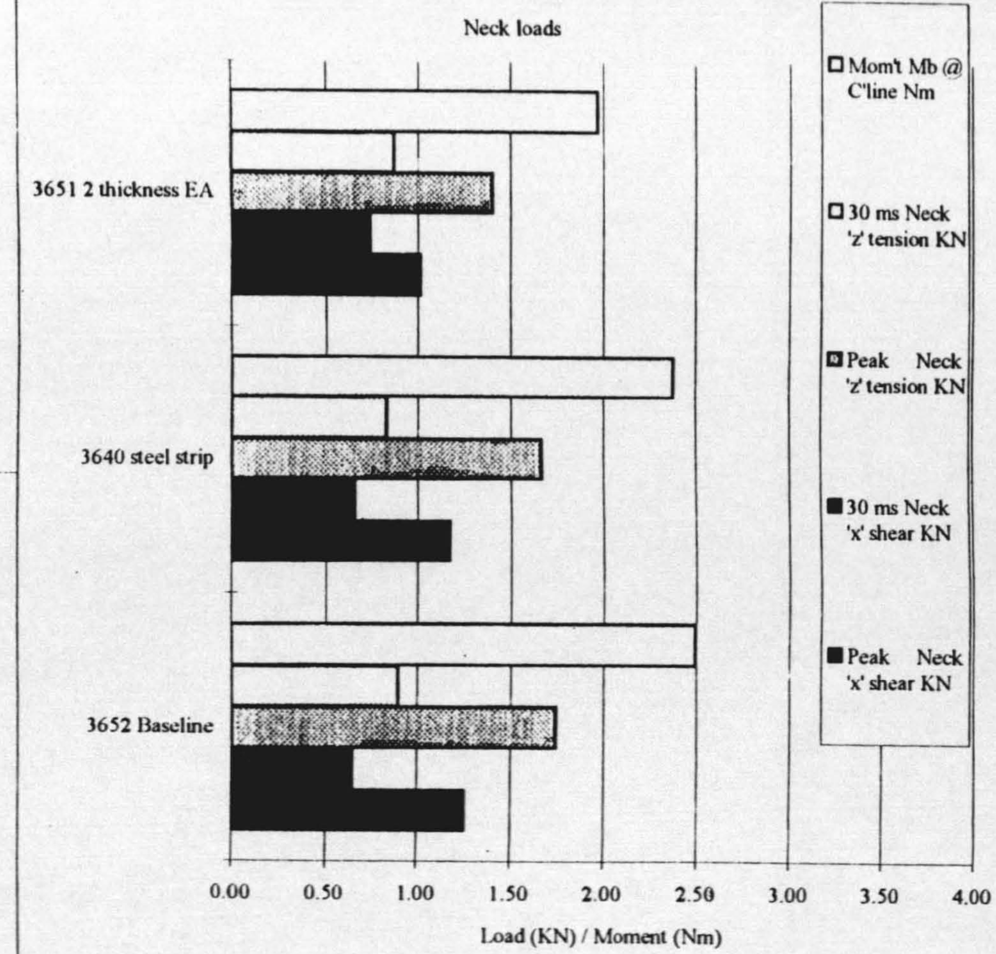


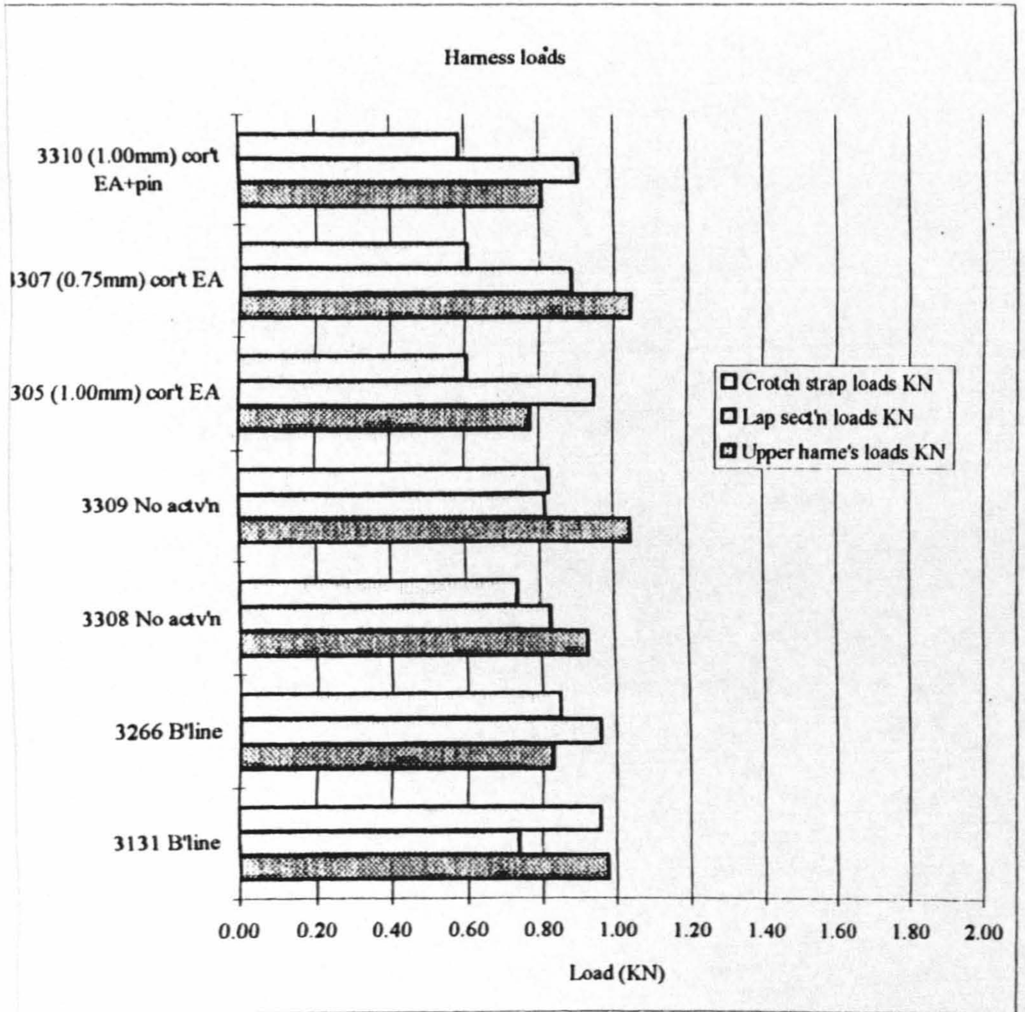


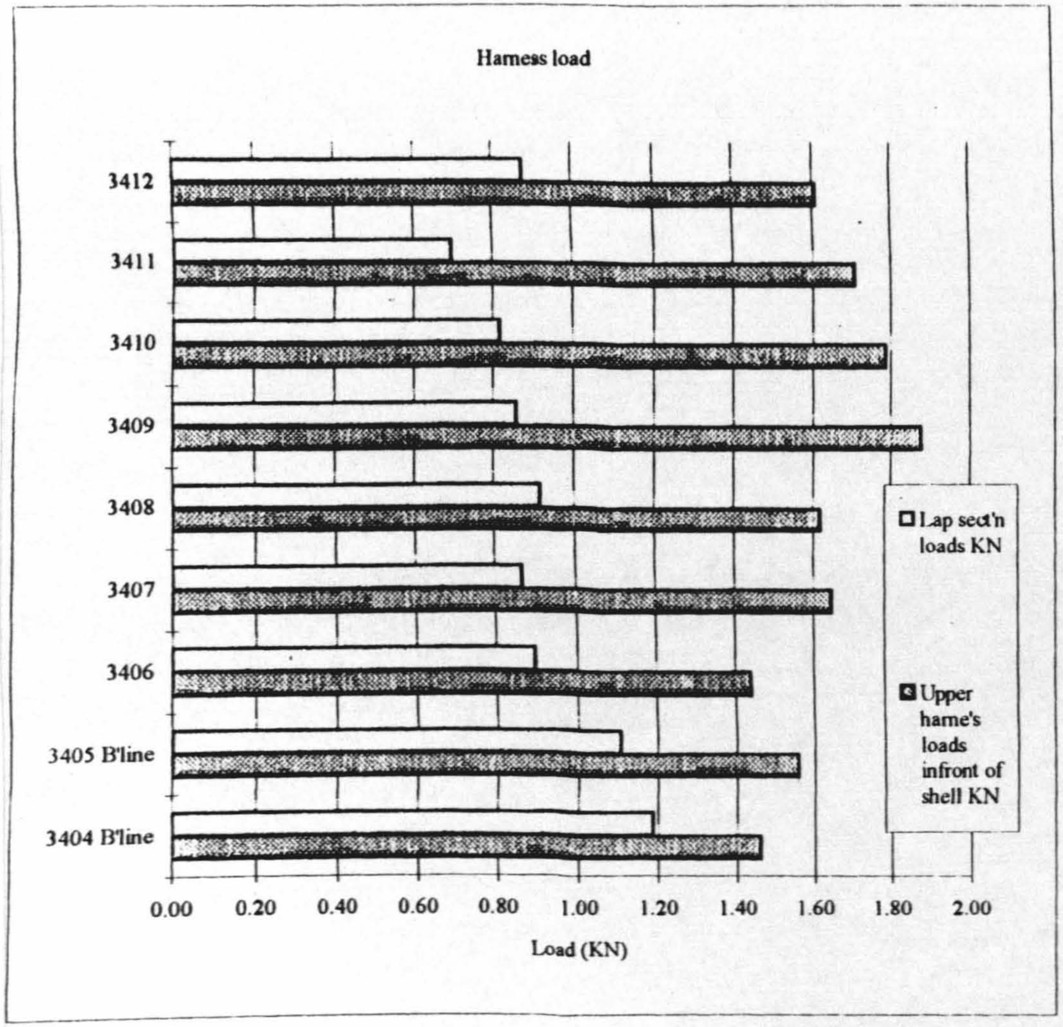
CANFIX **30°** **P3/4**








Harness loads
3310 (1.00mm) cor't EA+pin
3307 (0.75mm) cor't EA
3305 (1.00mm) cor't EA
3309 No actv'n
3308 No actv'n
3266 B'line
3131 B'line
Crotch strap loads KN
Lap sect'n loads KN
Upper harne's loads KN
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Load (KN)


Harness load
3412
3411
3410
3409
3408
3407
3406
3405 B'line
3404 B'line
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Load (KN)
Lap sect'n loads KN
Upper harne's loads infront of shell KN

9.0 DISCUSSION of RESULTS

It is appropriate to begin by remembering that this project was undertaken in order to provide an EA that could be used in conjunction with the ISOFIX concept if it proved that such a device was required.

Thus the final versions of the EA consisted of a one to be used in the single strap supporting the shoulder yoke in the current type of framed CRS or a four point ISOFIX , and the other to be used in the top tether of a two point anchorage ISOFIX concept CRS.

9.0.1 Criteria of Compliance with ECE Regulation 44 - 02 & 03

The limits for the P3 and P3/4 ATD used to test a system for a group 1 child are given thus :[<]
)

- 3ms values of Resultant Chest accelerations.[<55g] corrugated
- Tensile and Compressive chest Z acceleration component.[<30g]. [It should be noted that until recently the chest Z acceleration component referred to spine Compression. however currently the requirement has been changed to a neck Tension limit].
- Maximum Head Excursion.[<550mm].

In addition for the final tests on the Corrugated EA a neck load cell became available on loan from another test laboratory. Although no limits are defined for the neck loads in ECE Regulation 44 these results provide scope for comparison between the systems.

9.1 Types of EA

It will have been noted that five basic types of EA were investigated :

a)Aeroweb
b) Slotted plate with friction energy absorbing device
c) Slotted plate with polymer energy absorbing device
d) Metal shear type
e) Corrugated steel device.

The **type (e)- the Corrugated steel device** was the EA which was finally selected as the preferred device. as it required little tooling and it was thought that it would be cheapest to produce. In addition it could be manufactured in plastics or simply be fitted in a plastic case. Further the device has the benefit of simple adjustment for occupant mass.

However there may be other problems which would have had to be overcome in order to use the other devices commercially.

a) Aeroweb. -This device required the production of a piston and cylinder assembly . together with the purchase of expensive Aeroweb 'aluminium honeycomb'

c) and d) Slotted plate with friction or polymer EA were a modification designed by MURSEL to make a basic design by the late Mr R Singleton work.[This was our view and we found it difficult to persuade him to adopt our view] .However he felt that we would infringe his patent. we disagreed.

d) Metal shear type :-Renault published a paper at the 41st Stapp conference using a similar device in an adult belt. our device was predated by them. We are not sure if they have patented this device although we think it unlikely.

9.2 Analysis of Results

The full results are tabulated in Test Number order on pages 5-16. these are then tabulated as a function of EA type on pages 19 - 34; which are subsequently charted on pages 37 - 60.

In order to discuss these results in a meaningful way
summary sheets have been prepared on pages 1 - 5 of the data charted on pages 37 - 60.

These values for the defined parameters measured for CRS using EA are presented as ratios to the chosen base line CRS values. Hence any value less than 1.04 is considered to be either equal or an improvement for the CRS incorporating an EA.

Any ratio less than 1 is displayed in a *Leaf Green* box, whilst those between 1.01 and 1.04 are displayed in a *Light Green* box. Whilst those over 1.04 are indicated by a *Purple* box. Any value which exceeds. an ECE R44 limit is shown in a *Red* box.

Thus an EA which exhibited a performance improvement on a current Baseline CRS would be indicated by a line of *Leaf Green* boxes in which the ratio was less than unity.

The baseline CRS are indicated by shading.

9.2.1 PART 1 - Establishment of Performance of current CRS

These results have been used as the base line for comparison with the current CRS which incorporated the EA. As would be expected the results comply with the requirements of ECE Regulation 44 stated in paragraph 3.1.

9.2.2 PART 2 - Establishment of Performance of ISOFIX CRS

These results have been used as the base line for comparison with proposed 2 and 4 point Isofix CRS which incorporated EA's. As would be expected the results not only comply with but exceed the requirements of ECE Regulation 44 stated in paragraph 3.1.

9.2.3 PART 4 - Establishment of Performance of EA

In general therefore the EA have been installed either in the harness yoke or as part of a top tether.

In order to determine the crash performance of the different EA it was necessary to establish the baseline values of the parameters below using four and two point anchorage ISOFIX systems.

9.2.3.1 Performance of EA in ISOFIX four point anchorage systems harness CRS, P3 ATD'

The EA was mounted in the shoulder harness yoke of the ISOFIX four point anchorage CRS.

Reference to the summary pages [1 - 4] shows that the [Friction EA 3260]. the [Mk2 Polymer EA 1068]. the [Corrugated EA 3305] and the [Corrugated type with Shear Pin 3410; 3411] all comply with the specified ECE R44 Criteria.

It can also be seen that these show an improvement in performance over the base line tests except for a slight increase in head excursion This result would be expected as a reduction of chest accelerations has occurred.

9.2.3.2 Performance of EA in ISOFIX two point anchorage systems CRS P3 ATD

The EA was mounted as a top tether of the ISOFIX two point anchorage CRS

Reference to the summary pages[1 - 4] shows that the Corrugated EA [3583 Single thickness corrugation] and [3584 Double thickness corrugation].met the ECE R44 Criteria.

It can also be seen that these show an improvement in performance over the base line test [3582] except for 8% and 10% increases in head excursion respectively. This result would be expected as a reduction of chest accelerations has occurred.

9.2.3.3 Performance of EA in ISOFIX two point anchorage systems CRS P3/4 ATD

Reference to the summary page 3 shows that the Corrugated EA [3267 Single thickness corrugation]. [3628 Double thickness corrugation] and [3629 Treble thickness corrugation] met the ECE R44 Criteria.
When compared with the base line test [3626] the above EA [3628 and 3629] exhibit higher head excursions with slightly lower resultant chest accelerations[2%] and Z compression components.

After a number of alternative concepts were investigated. the Energy Absorber [EA] design was developed into two final versions using a steel corrugated element.
One to be used in the single strap supporting the shoulder yoke in the current type of framed CRS. and the other to be used in the top tether of a twin anchorage ISOFIX concept CRS.

It is appropriate to remember that this project was undertaken in order to provide an EA that could be used in conjunction with the ISOFIX concept if it proved that such a device was required.

10.0 CONCLUSION

10.0.1 Corrugated EA in harness yoke of four point ISOFIX

The results suggest that the four point anchorage ISOFIX system using a Corrugated EA in the harness shows a reduction in Head[0% - 10%] and Chest resultant [7% - 9%] and Z component[9% - 26%] accelerations when compared with the values obtained with the standard webbing harness. This is obtained at the expense of an increase in the head excursion of the order of 10% to 20%.. However the head excursion is still of the order of 30% below the 550mm limit required by ECE Regulation 44 - 03.

10.0.2 Corrugated EA as Top Tether in two point ISOFIX

The results suggest that the two point anchorage ISOFIX [CANFIX] system using a Corrugated EA as a top tether shows a significant reduction in Head[19% - 27%] and Chest resultant[12% - 23%] and Z component[0% - 40%] accelerations when compared with the values obtained with a webbing top tether. This is obtained at the expense of an increase in the head excursion of the order of 10%. However the head excursion is still of the order of 15% below the 550mm limit required by ECE Regulation 44 - 03.

11.0 REFERENCES

[1] Turbell T, Lowne R, Lundell B, Tingvall C (1993). ISOFIX - A New Concept of Installing Child Restraints in Cars. 933085

United Kingdom Delegation (WP29) Economic Commission for Europe Inland transport committee. Proposal for draft amendments (04) to regulation 44 to reflect Isofix. (1997). WP29/GRSP/1997/12.

[2] ECE R44 (Economic Commission for Europe Regulation No 44) amendment 03. Uniform Provisions concerning the approval of restraining devices for child occupants of power-driven vehicles (Child Restraints).

[3] Hill K J. Roy A P. Simulation of the Effects of Vehicle Impacts on Restrained Child Occupants - Part A: A description of the KL/MP Test facility. Journal of the Society of Environmental Engineers 21st March 1982.

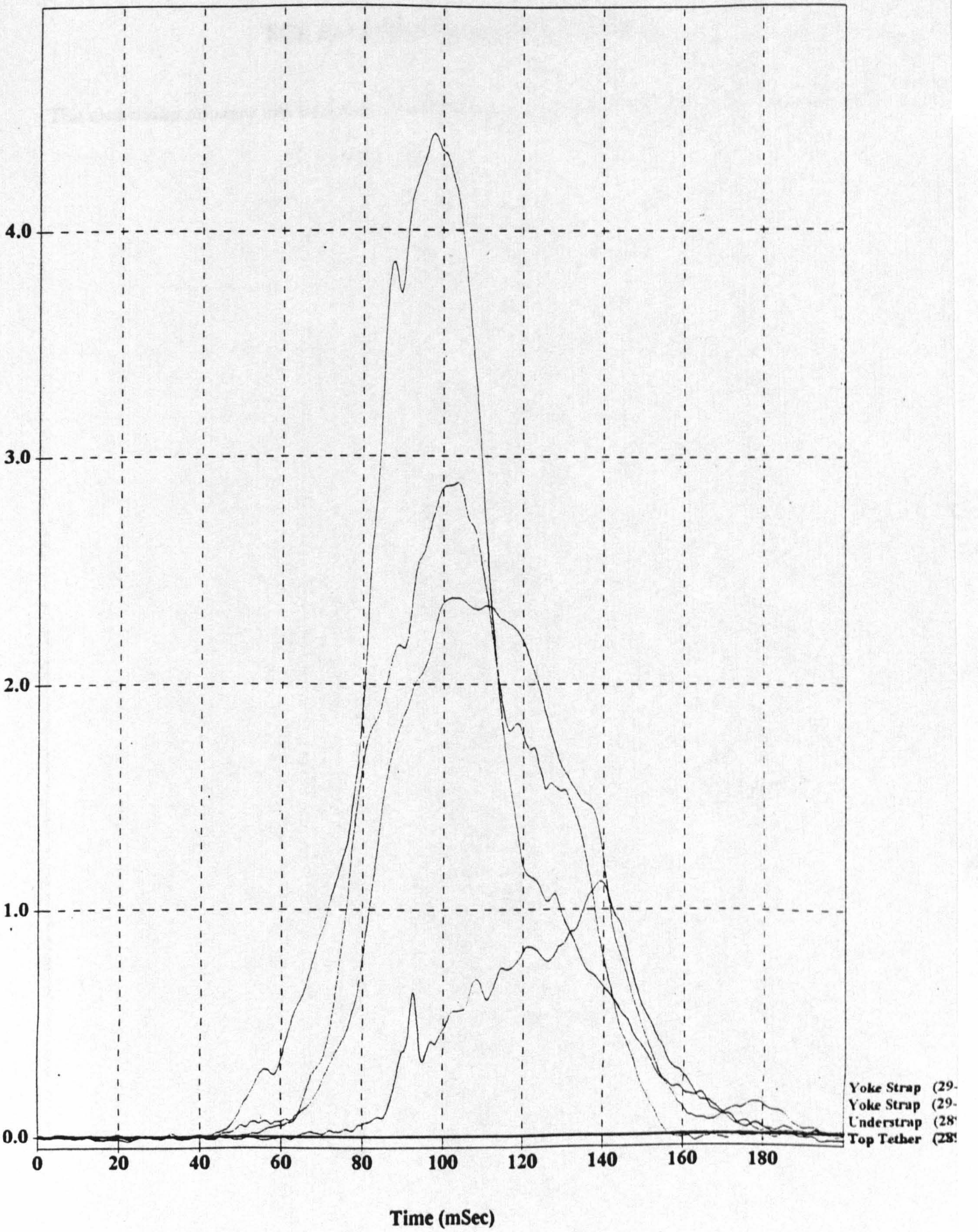
[4] Bendjellal F., Ventre P.,Bruno J Y V., et al(1997)., The Programmed Restraint System - A Lesson.from Accidentology. Paper973333.. Proc 41st STAPP Car Crash Conference. Orlando USA.1997 (SAE).

12.0 APPENDICES

12.1 Strap Loads

Middlesex University

Road Safety Engineering Laboratory



Appendix 6

ECE R44 COUNTRIES OF APPROVAL

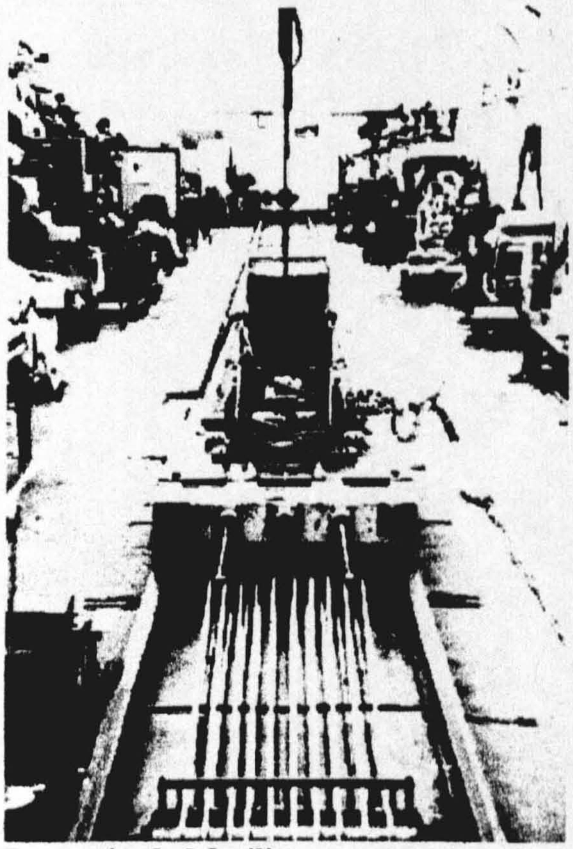
The approving country can be ascertained from the 'E' number found on the product. The list below shows participating members and associated E numbers

E1	Germany	E15	vacant
E2	France	E16	Norway
E3	Italy	E17	Finland
E4	Netherlands	E18	Denmark
E5	Sweden	E19	Romania
E6	Belgium	E20	Poland
E7	Hungary	E21	Portugal
E8	Czech Republic	E22	Russian Federation
E9	Spain	E23	Greece
E10	Yugoslavia	E24	vacant
E11	United Kingdom	E25	Croatia
E12	Austria	E26	Slovenia
E13	Luxembourg	E27	Slovakia
E14	Switzerland		

Road Safety Engineering Laboratory (RSEL)
Test Facility and Equipment

RSEL impact sled

The 40 metres long impact sled facility consisted of a rail mounted flat bed trolley (sled) restricted to only one degree of freedom (linear). Propulsion was achieved by means of elastic ropes (bungees), which when tensioned by an electric winch accelerated the trolley towards the retardation device at a predetermined rate, achieving the desired velocity immediately prior to impact. See figure below. It should be noted that at the point of impact, the sled had attained a constant velocity and was no longer subject to acceleration imposed by the bungees. Controlled deceleration of the sled was achieved by one of two deceleration devices interposed between the sled and a rigid fixture, comprising of a heavy steel upper frame firmly affixed to a 100 tonne concrete block below the floor of the laboratory. The performance characteristics of the deceleration device determined the nature of the 'deceleration pulse' experienced by the sled, this is commonly referred to as the sled pulse and would reflect the deceleration pulse experienced by the safety cage of a vehicle during an accident.



Dynamic sled facility

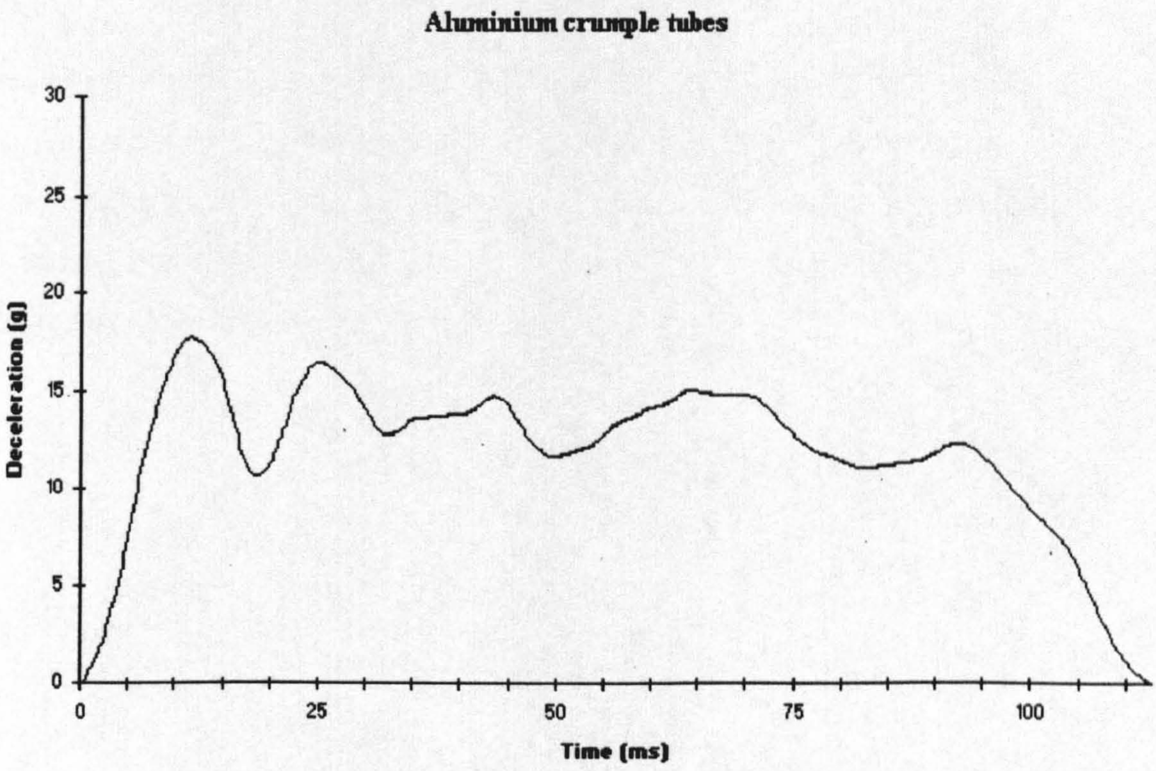
Deceleration regimes

European CRS acceptance standard ECE R44 calls for dynamic testing in frontal impacts to be conducted using a sled pulse whose parameters fall within a pre-defined envelope. To obtain the pulse, the test programme used polyurethane deceleration tubes. An alternative deceleration regime is available, namely aluminium crumple tubes. Both are described in the following sections.

Aluminium crumple tubes

To approximate the impact of a modern motor car, crumple tubes are employed to reproduce the effect created by the crumple zone of the vehicle. Crumple tubes are aluminium cylinders 1 metre long x 3"(75 mm) diameter x 0.075"(1.875 mm) wall thickness, which when impacted squarely on end by the sled, collapse in a manner consistent with local wave buckling theory, producing a sled deceleration pulse approximating a square wave. A sled pulse of this type is clearly the most desirable from a vehicle occupant's point of view as it has the minimum peak value, hence subjecting the car structure and adequately secured victims of an accident to an optimum level of deceleration and associated loading.

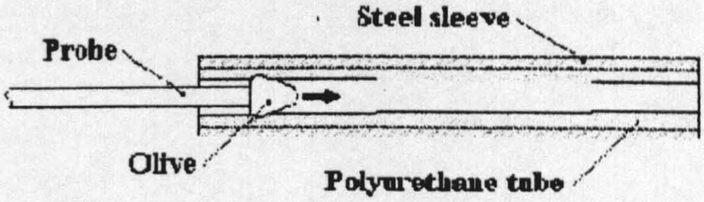
The figure below details a typical sled pulse achieved by use of crumple tubes.



Typical crumple tube deceleration pulse ΔV 50 km/h

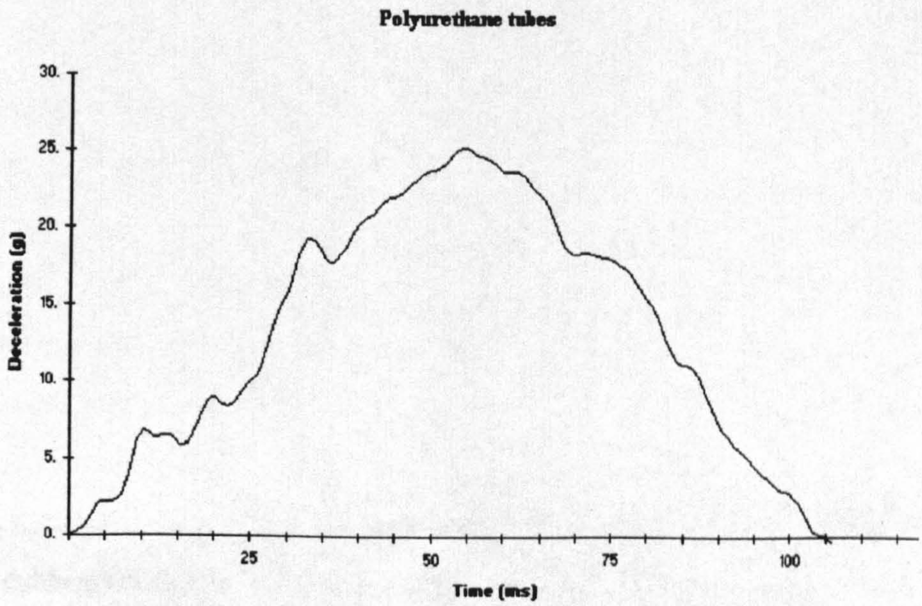
Polyurethane deceleration tubes

For practical reasons of cost and repeatability, a deceleration system employing internally tapered polyurethane tubes is widely used, in particular for certification purposes. The tubes, as many as five in number, dependent upon the mass to be retarded, are contained within steel liners affixed to the rigid structure at the end of the track. Positioned on the front of the sled are a corresponding number of metre long probes. Each probe has affixed to its end an olive having a diameter larger than the tube down which it is to be forced. The effect of forcing the olive down the smaller tapering polyurethane tube is to cause plastic deformation of that tube, producing a decelerating force upon the sled proportional to the number of tubes employed, the relative olive size and the ambient temperature in which the test is being conducted. The figure below details a section through the olive/tube assembly.



Section through deceleration tube assembly

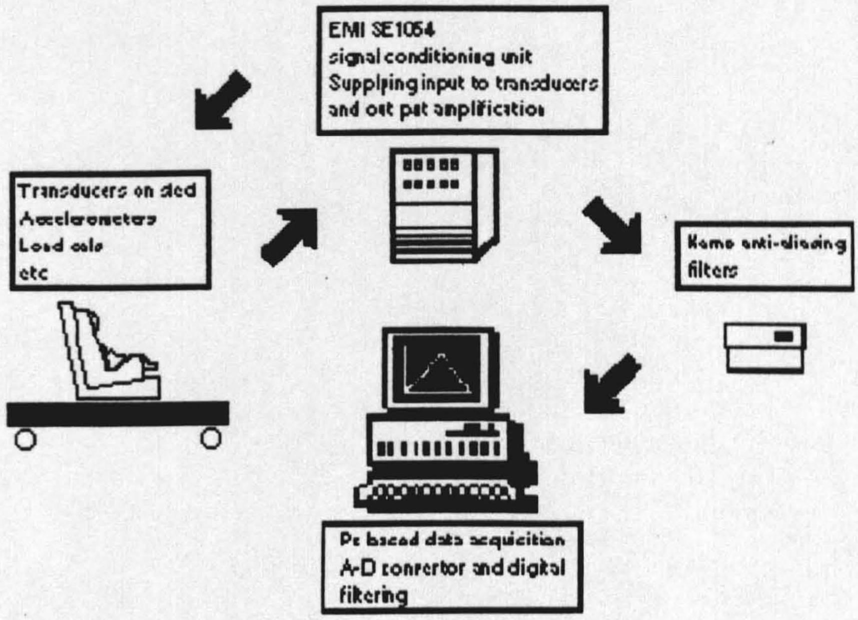
The sled pulse achieved by use of this deceleration regime approximates a 1/2 sin wave in form, and is not specifically intended to represent an actual vehicle deceleration pulse. It is, however, a repeatable pulse, which it is possible to reproduce (within certain limits) at any test facility, allowing for comparative testing. The figure below details a typical sled pulse achieved by use of polyurethane tubes.



Typical sled CRS test pulse achieved by use of polyurethane tubes ΔV 50 km/h

Instrumentation

The instrumentation employed at the RSEL facility conformed to the SAE recommended practice J 211 and is shown schematically below.



RSEL instrumentation

The transducers affixed to the components under investigation, such as the sled, seating system and manikin were supplied with input voltage (typically 10 v) from the signal conditioning unit. Output from the devices in the form of an analogue signal, collected over a maximum period of 400 milliseconds, was returned to the signal conditioning units via the connecting umbilical cables, amplified and passed to the Kemo anti-aliasing filters, then to the PC based data acquisition system.

Data acquisition cards within the system enabled conversion of the various channel signals from analogue to digital (rate 1000 samples/sec) the data being saved to hard disk as (.run) files. The cards being controlled by a software package called ASYST, which in addition facilitated subsequent manipulation of the digital data. The package enabled further filtering of the data in line with that called for in the standard being evaluated, in addition to finally enabling a calibration factor to be incorporated. The channel data was finally saved, again to hard disk as a (.con) file. With all the data saved as separate channels the data was then plotted, or exported to other software packages for further manipulation/analysis. In particular, x,y,z channel data from triaxial accelerometers commonly used in the manikins head and chest needed to be combined to provide a resultant acceleration for that particular section of the anatomy.

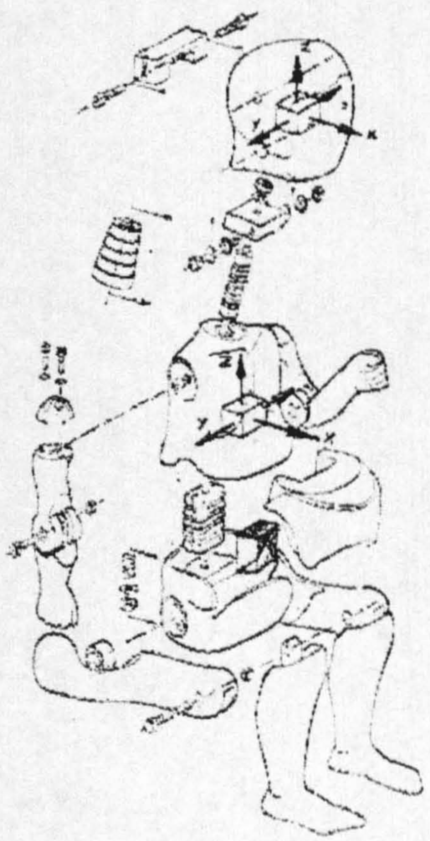
Transducers commonly used during the work in this study

Single axis accelerometer.

Used in applications where the item is going to accelerate or decelerate in a predetermined direction, enabling suitable positioning/orientation of the accelerometer, e.g. the sled.

Tri-axial accelerometer.

Used in applications where the orientation of the item is variable as the event unfolds e.g. the centre of mass of the manikin head and chest. The tri-axial accelerometers are usually mounted as shown in the figure opposite in the TNO P range of manikins. Sketch taken from manikin service manual.



Accelerometer locations

Denton belt load gauges

Used to measure the force applied to a webbing section of a belt system as it is loaded by the manikin etc. during a dynamic event. The gauge was of the three finger type, allowing it to be installed in virtually any belt system without modification to the belt itself. It does however result in approx 25 mm of extra belt per gauge being deployed in a system.

Dog bone load cell

This device comprised a bone shaped aluminium section with a strain gauged centre portion. It had holes at either end to facilitate its attachment, and was in this case employed in a bracket system to measure Isofix pin loads. This type of device is a simple single axis tool, capable of measuring only tensile loading between the pin jointed fixings.

Displacement transducers

Two types of displacement transducers were employed, the results being used to calculate resulting velocities. This was however only to verify velocities obtained by integration of accelerometer data. The two displacement transducer types used were of the radial and linear types.

High speed film/video analysis

To record kinematics of manikins and CRS etc. for post test analysis during a dynamic impact event which may be completed in less than 100 ms (typical for a 50 km/h event), it is necessary to record at a rate of at least 500 frames/sec. Two methods were available at MURSEL, high speed cinematography, capable of recording at up to 10000 frames/sec, and high speed video, recording at up to 6000 frames/sec (using split screen). The advantage of film is not only the speed, but the fact that the reproduction can be in colour, making analysis clearer and easier. The disadvantage of film is the time delay necessary whilst processing is conducted. The alternative to film is high speed video, used in almost all the tests reported in this study. The system, a Kodak Ektapro 1000 used a unique tape working at much higher spindle speeds than a conventional home VCR. The advantage of this system over film is the ability to replay the event immediately, allowing re-testing or modification to be conducted straight away should it be desired. The disadvantage is in this particular system the lack of colour making component definition somewhat more challenging during an analysis (note :- later video systems are available in colour). In addition to the turn round time advantage offered by the video, its digital output can be easily manipulated to allow transfer to PC packages.

Accuracy of measurement from the Video footage depended upon the proximity of the camera to the subject material, the image displayed being fixed at 240 x 192 pixels, measurements being possible to $\pm$ 1 pixel. Typically with the camera in the position used for CRS tests one pixel equated to 7 mm (although the actual value was measured during each test), hence the best accuracy of this system would be in the order of $\pm$7 mm as used during the majority of the tests in this study.